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A TECHNOLOGICAL REVIEW OF MODIFIED THEODOLITE INSTRUMENT: PHOTOTHEODOLITE

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Abstract: Theodolites are fundamental geodetic measuring instruments for all practical geodetic tasks, as well as for experimental geodetic scientific purposes. Their development has a long history. Photo and video theodolites represent the advanced development of classic theodolites. Development started in 19th century, but only in the last 15 years has commercial application been achieved in the geodetic profession. The latest development, called image-assisted total stations (IATS), is a theodolite which consists of a classic robotic total station (RTS) with integrated image sensors. It was introduced in the early 2000s. With the development of theodolites, their application became much wider; today, they can be used for structural and geo- monitoring, i.e., for the determination of static and dynamic displacements and deformations of civil engineering structures such asbridges, dams, wind turbines, and high buildings, as well as natural structures, such as mountain slopes

IndexTerms* - Theodolite, *Total Station,Civil Engineering,Geodatic

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I. INTRODUCTION

A theodolite is a geodetic instrument for measuring horizontal and vertical directions, i.e., angles in the horizontal and vertical plane. There are optical and electronic theodolites [1–3]. To determine the point positions in the coordinate system, in addition to angles, we must measure the distance between the instrument and the target. We can measure the distances mechanically (with chains and measuring tapes), optically (with optical distancemeters and interferometers), and electronically (with electro-optical distance-meters and electronic distance-meters (EDMs)). The accuracy of mechanically and optically measured distances is low and not appropriate for terrain characteristic point coordinate calculations. With time, several technological developments have been incorporated into theodolites; thus, the accuracy of angle and distance determination has significantly increased. Perhaps the biggest development of theodolites was its integration with an electronic distancemeter (EDM), which emerged around 1940 and became commercially available in the late 1960s [4]. The type of EDM incorporated into modern total station instruments is commonly of the electro-optical type, using infrared and laser light as a carrier signal [3]. Instruments which can measure angles and distances simultaneously, as well as record the results and to a certain extent, process them, are called electronic tachymeters or total stations (TS) [2]. TS instruments are electronic digital theodolites integrated with EDM instruments and electronic data collectors, which are aimed at replacing manual field data recording; they are capable of providing electronic angle readings, as well as distance measurements [3]. Today, many different sensors and measurement methods are combined in TS, such as highly accurate angle reading, electronic distance measurements (EDM) to reflectors and to any other surface (reflectorless EDM), tilt correction by two-axis inclinometers, different types of motorization to drive both the horizontal and the vertical motion of the instruments, servo, piezo, and magnetic motors (robotic total station—RTS), image CCD (charge-coupled device) or CMOS (complementary metal–oxide–semiconductor) sensors (CCD or CMOS) for autofocus, automated aiming (i.e., automatic target recognition (ATR) and tracking of signal points), integration with global navigation satellite system (GNSS) positioning, wireless communication and operation using a controller, additional cameras for documentation (image-assisted total station—IATS), and IATS with a scanning function (image-assisted scanning total station—IASTS). Due to the rapid hardware development, as can beseen in Figure 1, these different sensor classes, each with their specific advantages, can be unified, utilized, and are fused as one single (nearly) universal instrument [5]. Modern TS are multi-sensor systems which can determine the three-dimensional coordinates of target points by combining horizontal angle, vertical angle, and distance measurements [6]. Figure 1 shows the technological development of TS over the years, i.e., from the mid-20th century until today. The main hardware and software, sensor integration, and their impact on instrument performances and operator efficiency for conducting the measurements in the field are shown. It is evident that, following the integration of EDM with the basic theodolite in the 1960s upon discovering

tachymeters, the dimensions and weight of the instruments decreased, as well as the expert efficiency regarding the measuring techniques and time for conducting measurements in the field. Contrarily, instrument performance and the possibilities for surveying and monitoring projects have rapidly increased

Figure 1. Photo-Theodolite

II. LITERATURE REVIEW

Development during the 2000s placement emphasis on theodolite measurement systems (TMSs). ETs combined with integrated cameras, i.e., image CCD sensors, were used to measure spatial forward intersections using two or more instruments. The automatic aiming at fixed target points or projected laser spots was realized using image analysis techniques [8]. Most of these devices were used for industrial applications. In 1981, the Geodetic Institute of the University of Hannover took up the idea of using four-quadrant diodes as part of the Collaborative Research Center 149 within a subproject called "automatic determination of the position of an object at sea using a tachymeter". A semiconductor position-sensitive sensor built into the image plane of a tachymeter was used to detect the center of the light source located on a monitored ship. With the help of built-in servomotors, theinstrument could monitor the ship, always keeping the light source in the middle of the field of view (FOV). This development was based on the AGA Geodimeter 700, which had infinite screws for fine adjustment, named GEOROBOT, and GEOROBOT II was later developed on the basis of the Geodimeter 710 instrument [1,2].These instruments were developed through projects from Kernand Wild and were actually called Kern SPACE and Wild ATMS during the project phase. The growing demands of manufacturers in the automotive and aerospace industries, who used theodolite measurement systems during assembly and quality control, were based on measuring spatial forward intersections using two or more instruments. To satisfy these demands, Kern and Wild integrated CCD image sensors and digital image acquisition into servomotorized theodolites. These so-called video theodolites had panfocal telescopes, which means that the FOV changed as a function of distance to the target point. Kern E2-SE had a CCD image sensor with a resolution of 576 × 684 px, and the Figure 5. Contraves EOTS cinetheodolite (left)], AGA-Minilir cinetheodolite (middle) [24], and Krupp Atlas Polarfix (right) [2]. 2.3. Development from 1981–1990 Development during the 1980s placement emphasis on theodolite measurement systems (TMSs). ETs combined with integrated cameras, i.e., image CCD sensors, were usedto measure spatial forward intersections using two or more instruments. The automatic aiming at fixed target points or projected laser spots was realized using image analysis techniques [8]. Most of these devices were used for industrial applications. In 1981, the Geodetic Institute of the University of Hannover took up the idea of using four-quadrant diodes as part of the Collaborative Research Center 149 within a subproject called "automatic determination of the position of an object at sea using a tachymeter". Asemiconductor position-sensitive sensor built into the image plane of a tachymeter was used to detect the center of the light sourcelocated on a monitored ship. With the help of built-in servomotors, the instrument could monitor the ship, always keeping the lightsource in the middle of the field of view (FOV). This development was based on the AGA Geodimeter 700, which had infinite screws for fine adjustment, named GEOROBOT, and GEOROBOT II was later developed on the basis of the Geodimeter 710 instrument [7,8]. These instruments were developed through projects from Kern and Wild and were actually called Kern SPACE and Wild ATMS during the project phase. The growing demands of manufacturers in the automotive and aerospace industries, who used theodolite measurement systems during assembly and quality control, were based on measuring spatial forward intersections using two or more instruments. To satisfy these demands, Kern and Wild integrated CCD image sensors and digital image acquisition into servomotorized theodolites. These so-called video theodolites had panfocal telescopes, which means that the FOVchanged as a function of distance to the target point. Kern E2-SE had a CCD image sensor with a resolution of 576 × 684 px, and the image was recorded in the instrument's internal memory

III. MEASUREMENT AND PROCESSING APPROACHES

State-of-the-art IATS and IASTS represent a new kind of RTS, unifying the geodetic precision of TS with the areal coverage of images, as well as laser scans. IATS offer the user an image-capturing system with integrated camera(s) using image sensor(s) in addition to a polar 3D point measurement system. IASTS are equipped with a scanning function with lower scan rates comparable to classical terrestrial laser scanners. The greatest advantage of using such a (multi-sensor) instrument is the common coordinate system of all built-in sensors, as long as appropriate a priori calibration is provided . These multi-sensor systems can capture images for documentation and for photogrammetric measurements. They can even merge more of these captured images into a panoramic image mosaic using camera rotation, i.e., telescope rotation. With appropriate calibration, these images are accurately georeferenced and oriented, such that they can be immediately used for direction measurements with no need for object control points or further photogrammetric orientation processes [5].

IV. APPLICATIONS FOR VIDEO THEODOLITES

Monitoring of artificial or natural structures, i.e., civil engineering structures or parts of the Earth's surface, involves periodic or continuous observations to estimate the object's general current state regarding its usability and stability, as well as a determination of the need for structure remediation, reconstruction, or destruction. The process involves performing different kinds of measurements using different sensors. The measurements and results must be precise and reliable, i.e., accurate, and tested for significance [8]. The results of the measurements represent an important parameter in assessing the condition and safety of the structures, and this is especially important for structures used beyond their designed lifetime. Any kind of damage or significant deformation affects the safety of the constructions, e.g., bridges, dams, towers, or skyscrapers, and this can result in their closure or even collapse. Monitoring of artificial or natural structures is one of the key tasks in engineering geodesy, next to site surveying and setting out. Geodetic monitoring is one aspect of monitoring systems in general. There are two subtypes of geodetic monitoring [8]: • Structural monitoring refers to the measurement and evaluation of civil engineering structures such as bridges, tunnels, dams, railways, towers, or skyscrapers, i.e., generally manmade objects. • Geo-monitoring, in contrast, is used as a term for the determination of changes, movements, or deformation of natural structures, such as landslides and slopes. The main aim of geodetic monitoring is to determine statistically significant geometric changes in size, shape, and position between two or more measuring epochs. According to the monitoring data, action can be taken on the construction to prevent material and nonmaterial damages. Vibration-based monitoring, i.e., structural monitoring, has become common recently. Vibration-based monitoring consists of determining the dynamic displacements and natural frequencies of objects from different epochs of measurements. Any changes from the designed frequencies can be a sign of structural damage and a cause for alarm. Dynamic displacements and natural frequencies of objects can be determined by RTS and GNSS instruments, although their use in these projects has certain limitations. The limitation of the first RTS models was their instrument measurement frequency of 1 Hz, which was lower than the fundamental frequency of the bridge, as demonstrated in [5]. Possibilities of newer RTS models with measuring frequencies of 5–7Hz were presented in [66–70], where RTS instruments were used for the measurement of simulated dynamic displacements to analyze the accuracy of dynamic measurements by RTS, as well as for the determination of dynamic displacements and natural frequencies of bridges in exploitation. The accuracy of an RTS instrument with 20 Hz measuring frequencies for recording changing 3D coordinates of a moving target was tested in [1] and for measuring dynamic displacements and natural frequencies ofrailway bridges in , where the RTS determined dynamic displacements of the bridge in vertical and lateral directions and the first five natural frequencies of the bridge. To overcome the limitations of RTS measuring frequencies, a new approach was shown in [6], where the authors demonstrated how to increase the measurement frequencies of an RTS instrument from 7–10 Hz to 20 Hz.

V. CONCLUSIONS

With the development of EDM and the principle of the difference in two currents in a photoelectric cell, static targets could be recognized and measured with high accuracy. Appl. Sci. 2021, 11, 3893 25 of 29 The developed image sensors were then integrated into the theodolites and their purpose changed from mapping to object tracking. The demands of the automotive and aerospace industries regarding assembly and quality control in the 1980s forced companies to build electronic tachymeters with integrated image sensors into servomotorized theodolites. The greatest contribution from this development line was that image sensors were used for autofocusing and for determining the target position relative to the optical axis of the telescope. Although the technological development of commercial instruments slowed down in the 1990s, the academic community maintained research efforts and developed the applications of digital image processing methods and computer vision, which have been preserved to this day. Initial research focused on detecting artificial targets and accurate aiming with the help of cameras for the purpose of aiming and measuring unsignalized targets. Solutions based on artificial intelligence were developed. By implementing the expert knowledge of sighting points into software solutions, artificial intelligence was applied, and expert systems were developed. The developed algorithms were later implemented in commercial instruments. By automating the measurements, the level of achieved accuracy was increased.

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