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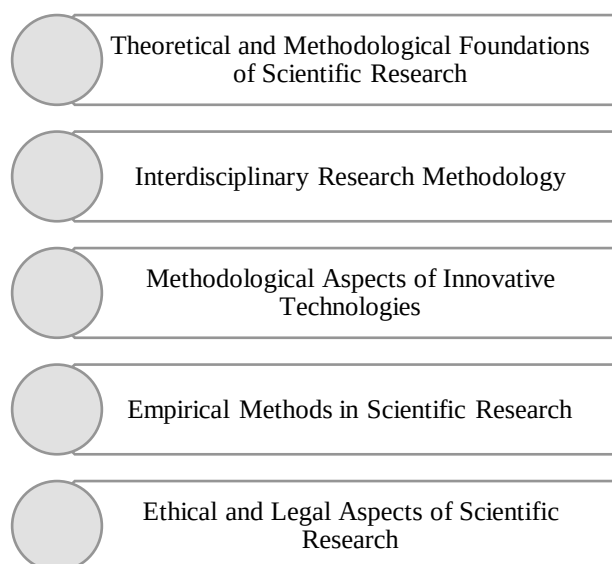


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DEVELOPMENT AND RESEARCH OF A COMBINED 3D SCANNER WITH PRECISE DETERMINATION OF THE GEOMETRY OF DARK AND TRANSPARENT OBJECTS

Abstract. The architecture of a combined non-contact 3D scanner is proposed, which combines structured lighting, polarization imaging and an auxiliary depth channel (ToF/stereo) for reliable measurement of complex surfaces – superblack, shiny and transparent. A consistent sequence of calibrations, channel matching algorithms and glare screening, as well as rules for switching modes to the material and scene conditions are described. It is shown that the use of cross-polarization and multi-turn phase Depth safety coding increases the stability of phase deployment and reduces errors in high-contrast areas. An example of hardware configuration and a table of recommended modes for typical materials are given. The solution is focused on engineering metrology, restoration of cultural heritage and quality control of glass and polycarbonate products, where standard methods fail due to pixel saturation or refraction.

Key words: non-contact measurements, structured radiation, polarimetry, time-lapse depth, glare reduction, multimodal registration.

Introduction. The task of accurate 3D reproduction of complex materials (with low reflection (super-black coatings), with a significant mirror component (polished metals) and with transmittance (glass, PMMA) remains open to most commercial scanners. double passages through the boundaries of the media [1–3]. More recent work also demonstrates the usefulness of merging depth sensors (ToF/stereo) with structured lighting to resolve ambiguities and phase deployment in problem areas [4].

In Ukraine and the world, polarization cameras and cross-polarization schemes that suppress mirror reflections and increase the contrast of bands are being actively studied; For transparent bodies, combinations of polarimetry with stereo vision or laser scanning are offered. However, such approaches often depend on harsh lighting conditions, have ambiguity at the zenith angle, or require complex calibrations of multi-channel sensors, which makes repeatability and portability between scenarios difficult [2, 5]. Therefore, a practice-oriented system is needed that coordinates channels, minimizes reflection and refraction artifacts, and automatically selects the shooting mode.

The article is aimed at describing the hardware and software architecture of the combined scanner and the methods of its operation with recommendations for modes for different materials, based on modern developments in polarized structured light, reconstruction of transparent bodies and fusion of deep sources [1–4].

Consider the architecture and measurement channels. The scanner consists of a structured light projector with controlled polarization, an RGB or monochrome camera with a rotary analyzer, an auxiliary depth channel (ToF or stereo pair), a synchronization unit and a rotating platform for multi-view shooting. Basic patterns (multi-frequency phase bands) for reflective surfaces are projections of polarized bands with four-channel polarization reading. This combination increases resistance to overexposure and "dips" in shadows [1, 2].

To coordinate the calibration procedure, the following sequence is proposed: internal calibration of the chambers or projector (through a chessboard and phase templates); polarization zero-setting (cross-polarization to estimate leakage); joint calibration of the depth channel with the visual channel (through rigidly fixed targets and multi-plane scenes) – for correct geometric registration and scaling [4, 6].

The algorithmic processing pipeline is as follows. After synchronous readout, the frames undergo HDR fusion of exposures, polarized band orientation estimation, phase demodulation, and spatial unfolding using a rough depth map from ToF or stereo as hints. Next, local point clouds are combined from different angles and their joint optimization is performed. For transparent objects, a "refractive mask" is added - cutting off rays with an inappropriate polarization vector [1, 3, 5].

Switching rules were also proposed: for super black - increased projector power, multiple exposures; for mirror – cross-polarization and reduction of the contrast of the stripes; for transparent ones – polarized structured light with safety depth and multi-species registration [1–3].

An example of the configuration of the hardware part **of the combined scanner is given in Table 1, and** the recommended modes for typical materials are given in Table 2.

Table 1. Example of Combined Scanner Node Configuration

Knot	Example of parameters or requirements	Reason for choosing
Structured Light Projector	LED/NIR, Controlled Polarization, Multi-Frequency Patterns	Overlight control, polarimetry compatibility
Camera	(mono) polarizing, global shutter, variable filter	Minimize blur, suppress glare
Deep Channel	ToF or stereo (60-120mm base)	Hint for phase deployment, recovery of dips
Sync	hardware triggers, TTL	Phase and exposure matching
Sample rotation	360°, deterministic pitch	Closing "dead zones"

Table 2. Selection of modes for the material and condition of the scene

Material or condition	Lighting	Polarization	Deep Channel	Comment
Super black, matte	High intensity, multi-frequency bands	Off	ToF and stereo enabled	Reducing Shadow Dips
Polished metals	moderate intensity	Cross	as needed	Glare suppression, stable phases
Transparent (glass, PMMA)	polarized stripes	crossover + channel analysis	Preferably	Cutting off rays with refraction
Variable lighting	NIR band	Behind the Scenes	Preferably	Desensitization to backlights

Consequently, polarized structured light confirms performance on mirror surfaces, and for transparent bodies, modern robots use a combination of polarization prompts and stereovision and machine learning; The 2022–2024 reviews capture these trends and note challenges – dependence on lighting geometry, ambiguity of angles, and demanding calibrations [2, 3, 5]. The addition of a depth channel removes some of the ambiguities and facilitates phase deployment in high-contrast areas [4].

Conclusions. The proposed combined architecture aligns the advantages of structured light, polarimetry, and ToF and stereo, making measurements resistant to glare and transparency.

The described sequence of calibrations and mode switching rules ensure repeatability and portability between scenes.

Recommendations for settings for different materials allow you to practically implement the system in metrology, restoration and quality control of glass or polycarbonate products.

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