Holographic mirror-based approach in augmented reality glasses

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ABSTRACT

In the last years many efforts have been invested in the development of augmented reality devices. Depending on the application different constraints need to be faced. Providing full color see-through augmented reality on eyeglasses with ophthalmic correction, and valid for a wide range of use cases, is one of the most challenging and ambitious applications. We are within a European Project aiming to this goal. One of the key components in this eyewear is the holographic lens mirror (HLM), acting as the beam combiner responsible for the see-through capability. In this work, we present the main goals of this European Project and, more specifically, the holographic approach being developed for the HLM within our research group.

Keywords: Holographic optical elements, volume holography, coupled-wave theory, augmented-reality

1. INTRODUCTION

Holography has the unique capability of capturing the whole information of a propagating wave in a recorded interference pattern, and then playing it back when the correct reconstruction wavefront is used to illuminate [1]. In this way holographic optical elements (HOEs), as the holographic mirrors (also called Holographic Lens Mirrors - HLM) of interest in this work, can be produced onto a thin film of photosensitive material, typically photopolymers [2-4]. When onto a transparent substrate, such as in a prescription (Rx) lens, the HLM has the same characteristics as a partial reflecting mirror but without its brightness and contrast limitations since ambient light does not comply with Bragg's law and is not deviated [5]. Literature dealing with HLMs onto curved surfaces shows mostly the cases of big form-factor devices, such as helmet-mounted displays [6,7], thus the case for light augmented reality eyewear (ARE) is at present a research topic with great potential for applications and almost unexplored [8].

In ARE the design of the HLM is challenging since the microdisplay for reconstruction is placed highly off-axis, increasing astigmatism/coma aberrations, which are open problems to be faced [5,9-11]. All these are important considerations that we are taking into account presently in an ambitious European Union (EU) funded project. The European Project POPULAR [12], acronym for Prescription Optics providing a Universal Lens for Augmented Reality Eyewear, aims at developing the first generic Augmented Reality Eyewear (ARE) platform covering the widest range of users and use cases, in professional context, leisure, or in daily life. The global objective is that ordinary-looking glasses will provide visual, wearable, vestibular, mental and social comfort, making them suitable for all-day use, including personal ophthalmic correction, which will enhance society and market acceptance.

In this work we present the main goals and description of the POPULAR project, and more specifically the characteristics and methodology in the development for the HLM.

Optics and Photonics for Information Processing XVIII, edited by Khan M. Iftekharuddin, Abdul A. S. Awwal, Victor Hugo Diaz-Ramirez, Andrés Márquez, Proc. of SPIE Vol. 13136, 131360S

2. GOALS AND AMBITIONS OF THE POPULAR EU FUNDED PROJECT

The global objective of the EU funded POPULAR project is that ordinary-looking glasses will provide visual, wearable, vestibular, mental and social comfort, making them suitable for all-day use, including personal ophthalmic correction, which will enhance society and market acceptance. Major innovations are related to compactness and invisible technology, optical quality, ultra-low power consumption and long operation times, integrating cost efficiency aspects as well. Social Science and Humanities (SSH) aspects [13] will be considered in all stages of the project by using a dual approach with an interplay between human-driven Design and multidisciplinary system engineering through iterative prototype testing, combining Human Factors (HF), User Experience (UX) and Lean methodologies. Demonstration will be achieved by performing end-user tests with the prototypes in 3 realistic use case scenarios: outdoor sports, healthcare, and logistics.

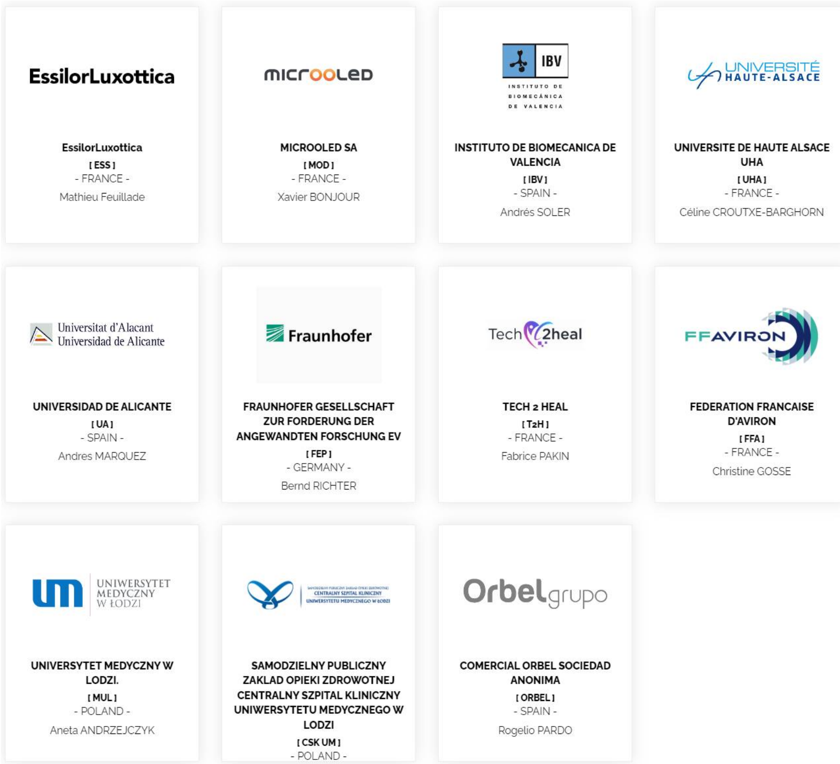

Figure 1. Logos and basic data of the partners in EU funded POPULAR.

POPULAR project provides a unique chance for the European industry to become a leader in the growing market of ARE, building on its worldwide leadership in the Eyewear industry and its strong R&D and Innovation capabilities. The consortium is a unique combination of cross-functional experts, representing the entire value chain. It consists of 10 partners from 4 EU countries, including 4 research and academic centres, 3 industrial companies of which 2 SMEs, and 3 use-case partners. The individual objectives of POPULAR can be synthesized as follows:

- Ultra-low power (< 8mW) and high-luminance (target is 10 000cd/m²) RGB colour OLED microdisplay devices.
- High-performance holographic material and customizable holographic lens mirrors compatible with any type of corrective lenses.
- Eyewear system integration with enhanced AR performance (1000 cd/m² RGB colour), reduced size.
- Create societal acceptance and motivate stakeholders and users for adoption, reaching >80% of acceptance of potential users, including people with disabilities.

- Demonstrate at TRL5 the short-term deployment potential and scalability of the proposed solutions/prototypes validated in realistic scenarios especially in healthcare, logistics and outdoor sports sectors.

To implement this ambitious project, there is a dedicated team composed by 10 partners (shown in Fig. 1): EssilorLuxottica (coordinator), MICROOLED, Instituto de Bimecanica de Valencia, Université de Haute-Alsace, Universidad de Alicante, Fraunhofer, Tech2Heal, Fédération Française d'Aviron, Universytet Medyczny w Lodzi and Comercial Orbel. In Fig. 2, we show an explanatory diagram of the technological path and the interactions between the different partners in the consortium to bring to reality the concept for the ARE described.

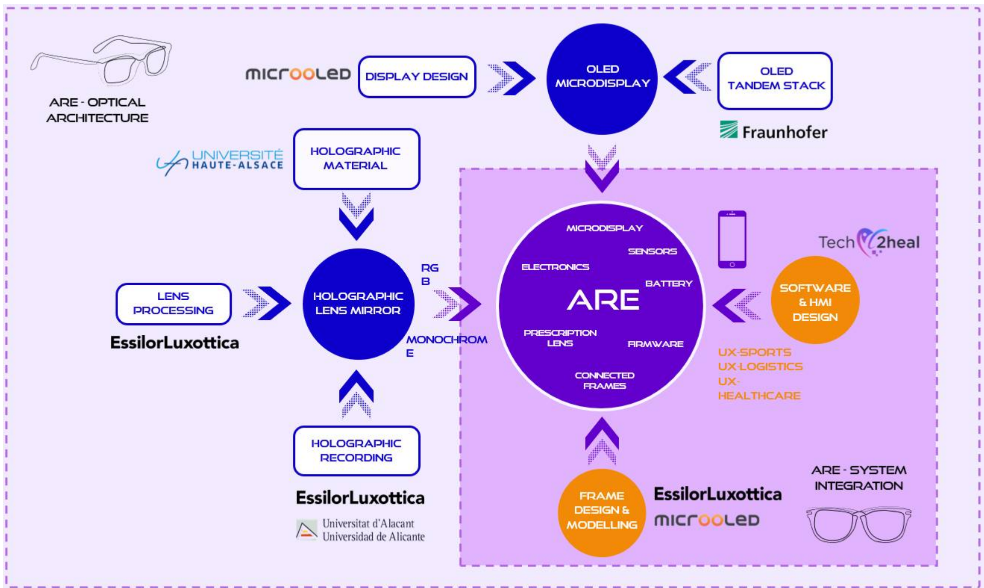

Figure 2. Explanatory diagram of the technological path and interactions with the POPULAR consortium.

3. HOLOGRAPHIC MIRROR FOR POPULAR

An elegant way to bring the virtual information in front of the eye of the wearer without disturbing his vision through the device is to propose a transparent mirror with a non-classical specular reflection. It is a holographic lens mirror. This HLM will be designed especially for the used display and the eyewear, will fit to the curvature of the lens, and will adapt the virtual information to the visual acuity of the wearer for a comfortable usage of this ARE.

Volume holography unique capabilities are central in POPULAR to propose a customizable HLM compatible with any type of corrective lenses for a comfortable visualisation of virtual image and real world without unesthetic eye glow, the development of a high-performance holographic recording material is mandatory. It should have excellent stability, transparency and efficiency, together with chemical and process compatibility with standard ophthalmic coatings. Robust HLM fabrication and evaluation setups with tunability of wavefront curvature adapted to the substrate geometry, OLED position and user prescription is also required.

To guide these activities, numerical modelling needs to be performed to understand the holographic recording and optimize the recording and evaluation setups.. For the simulation of HLMs, some strategies can be followed for the light propagation simulation step, i.e., Kogelnik's Coupled Wave, Rigorous Coupled Wave (RCW) or Finite-Difference Time-Domain (FDTD) [14,15]. The applicability of these numerical techniques must be analysed due to the accuracy limitations (Kogelnik's theory versus RCW) and computation requirements (FDTD, Finite-difference time-domain), leading to an optimized approach adapted to guide the design of the holographic material and the HLM recording geometry. At this regard, the spatial variance of the fringe period is generally much smaller than the fringe period itself, so the local region can be treated as a grating. This is used in this project to study the basic diffraction properties of gratings of the aforementioned HOEs. Both the spectral and angular dependences of the first-order diffraction efficiency are calculated.

In the following we show some preliminary results obtained according to the exposed methodology using the commercially available Bayfol HX200, from Covestro [4], which serves to validate the basic concepts and the setups. In Fig. 3(a), we show the scheme of the HLM recording with the beams incident onto the photopolymer at 0º and 40º respectively, both collimated (plano/plano), and using a laser at 532nm wavelength. In Fig. 3(b) and 3(c) we show respectively a qualitative view of the replay with white ambient light, and the spectral transmission measured in a spectrometer. We clearly see that the light scattered is in the green region when white light is incident at the Bragg angle. In a more quantitative way, in Fig. 3(c) we see the loss of transmitted light at about 525nm, with a full-half maximum width (FHMW) of about 15 nm. The shift between the recording and the reconstructed wavelengths is 7 nm, due to the shrinkage of the photopolymer after exposure. This is about 1% shrinkage in the layer thickness (which initially is 16 µm for the Bayfol HX200) [16]. This is a very important parameter to be considered to design accordingly the OLED microdisplay used in the POPULAR project.

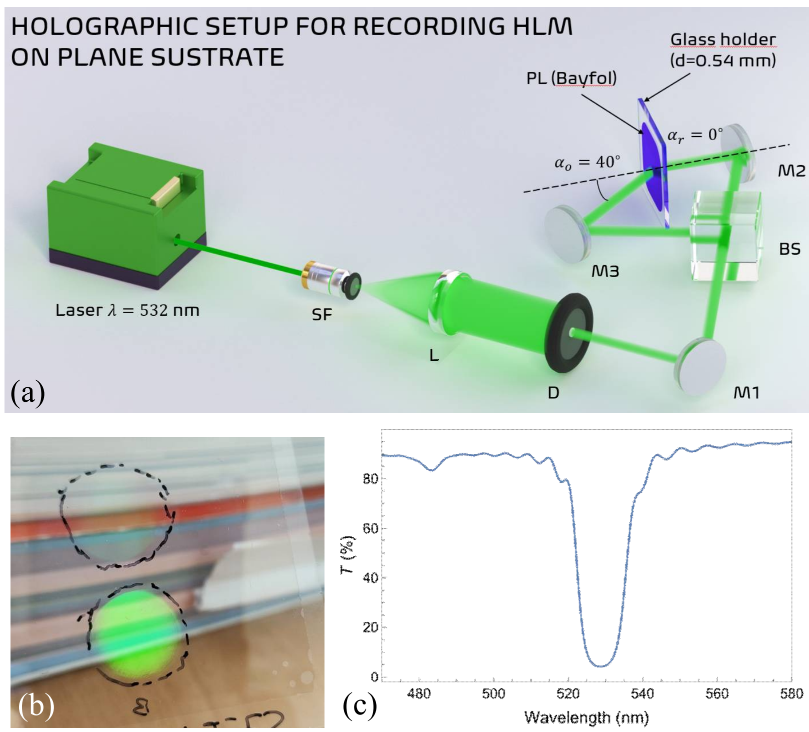

Figure 3. (a) Scheme of the recording setup for a slanted plano/plano HLM at 532 nm, (b) Reconstruction with white ambient light at the Bragg angle, and (c) Spectral plot for the light transmitted by the HLM at Bragg angle measured in a spectrometer.

In the project, the substrate for the photopolymer is in general the curved substrate of Rx lenses. We have laminated by thermoforming [17,18] the Bayfol HX200 onto these curved substrates, to test our experimental systems. In Fig. 4 we show the results when recording a plano/plano slanted HLM equivalent to the ones in Fig. 3, but now on the curved lens substrate. In this case we have used a 514 nm wavelength laser. In Fig. 4(a) we show respectively the view of the HLM when illuminated with the white ambient light to see the homogeneity of the diffracted wavefront. In Fig. 4(c) we show the spectral response in transmission, with a shift a blue-shift from the recording wavelength as in Fig. 3. We observe a second dip in the spectral curve that might be due to secondary gratings recorded due to internal reflections. Further research is ongoing on this.

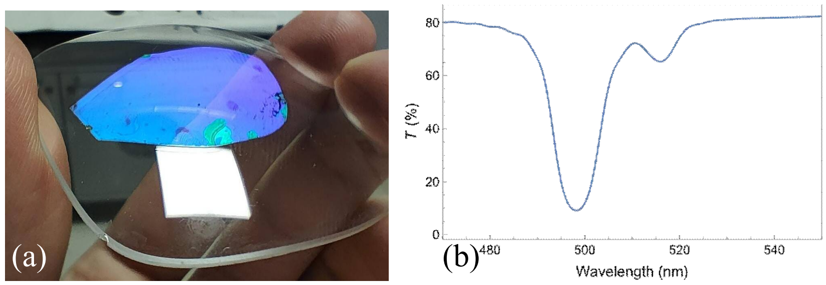

Figure 4. Slanted plano/plano at 0º/40º HLM recorded at 514 nm on a curved substrate. (a) Reconstruction with white ambient light at the Bragg angle, and (c) Spectral plot for the light transmitted by the HLM at Bragg angle measured in a spectrometer.

4. CONCLUSIONS

We have presented the main goals and ambitions of the EU funded POPULAR project and described the scientific and technical methodology in which it is based. Some preliminary results dealing the recording and reconstruction of the HLM both on flat and on curved substrate have been shown. The project started on the 1rst of January and has a duration of 3 years, along which the 10 partners composing the consortium will need to face the many challenges existing provide light ARE with ophthalmic correction and valid for a wide range of use cases.

ACKNOWLEDGEMENTS

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101135770. This publication reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein. The authors would like to thank all partners of Popular Consortium (Fig. 1).

Funded by the European Union POPULAR

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