

# Wireless Sensor Glove Interface and its Application in Digital Holography

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**Abstract**— In the paper we introduce the novel intuitive user interface (UI) which is based on Wireless Sensor and Actuator Network (WSAN) technology and is implemented as a glove with a set of sensors for capturing user's gestures. The proposed UI is applied for interacting with a conventional 3D display and controlling the reconstruction of digital holograms. To the best of our knowledge the suggested interface is the first one, which is intended specifically for controlling the reconstruction parameters of digital holographic data. The suggested system includes the inter-cognitive communication as an important design parameter. In the paper we discuss in details the implementation of the interface and present the results of the experiments, in which the suggested UI was used to control the reconstruction of the holograms depicting industrially manufactured 3D objects. Based on the presented results, we distinguish the features of the developed UI and discuss the possible industrial applications of digital holography and of the suggested interface.

**Keywords**—user interface; digital holography; glove; sensor networks; 3D display; anaglyph; reconstruction; control;

## I. INTRODUCTION

Holography is a method for recording and reconstructing both amplitude and phase of a wavefront. It was originally invented by Dennis Gabor while he was investigating methods how to improve poor resolution of an electron microscopy [1]. His invention formed the base for optical holography which gained more attention after invention of the laser in the 60s. Typically, holography requires two stages: recording and reconstruction. In the recording stage an interferogram formed by two beams, an object and reference beam, is captured on a recording medium. In the reconstruction stage the very same hologram is exposed to a light and the object can be viewed with an eye. In theory, as the hologram is a record of the full wavefront, the viewer cannot tell the difference between the original object and the hologram reconstruction.

In traditional optical holography the recording medium is a holographic plate which requires chemical processing after the actual capturing stage. Digital holography became possible after the digital camera sensors evolved at mature enough state [2]. Digital holography overcomes some drawbacks related to conventional optical holography such as chemical processing, cumbersome transportation, weak protection and limited processing capabilities. In digital holography the recording

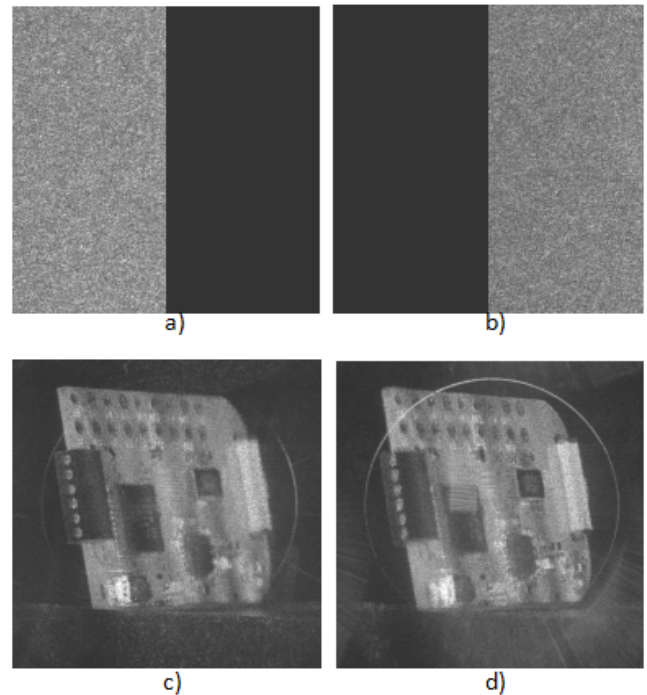


Fig.1. Properties of a digital hologram a) and b) show portion of a hologram used to reconstruct left and right perspectives, respectively c) the reconstruction from left perspective (focused at 230 mm from the camera) d) the reconstruction from right perspective (focused at 249 mm from the camera). Horizontal viewing angle separation between the objects depicted in c) and d) is around  $0.7^\circ$

medium is replaced with a digital sensor such as a charged-couple device (CCD) camera or complementary metal oxide semiconductor (CMOS) camera. Therefore the wavefront is digitised, which enables easy holographic data transfer (over network) and direct digital processing (*e.g.*, numerical reconstruction and compression). The digital holography has been used in various applications from biology to industry. Downside of using these sensors is a limited resolution, which is dependent on the pixel size and the size of the actual sensor.

Recording the full wavefront enables some special holographic principles/properties. Unlike conventional photography, digital holography enables viewing an object from different perspectives and at any depth of the captured scene (see Fig. 1 for example). All this is achieved from a single captured hologram. Amount of available views depends

on the used camera sensor. As the diameter of the modern digital camera sensors is around 10 mm, amount of views in a single digital hologram is restricted to few degrees. Use of multiple cameras enables one to increase the number of views by capturing multiple holograms from different perspectives [3].

A digital hologram can be reconstructed either optoelectronically with a use of LCoS (Liquid Crystal on Silicon) 2D spatial light modulator [4,5] or numerically and displayed on a conventional 2D screen [6]. The optoelectrical reconstruction setup is a true 3D display enabling multiple views and freedom to focus at any depth of the captured scene. However these displays are mostly used in scientific and research purposes and are not commercially available for actual display purposes. The state-of-the-art true 3D displays have some drawbacks such as limited amount of views, small size of the reconstructed object and laser safety issues. Because of these issues conventional 3D displays and numerical reconstruction can be used to display the digital holograms. Numerical reconstruction is a realisation of a computer algorithm which simulates propagation of light from the hologram [7].

Conventional 3D displays can be based on various technologies. Typically these displays are stereoscopic displays providing two different views of an object. These two views are merged by the human brain and give a 3D impression to a viewer. Techniques behind stereoscopic displays can be based on:

- anaglyphs,
- polarisation and glasses,
- shutter glasses,
- mirror based (such as. Wheatstone apparatus),
- lenticular lens.

As a single digital hologram encodes different perspectives of the captured scene, digital holograms can be used easily with displays which require different views of a scene as an input. By using various portions of the holographic data different perspectives can be reconstructed (see Fig. 1). Use of this special property has been reported with conventional displays for reconstructing one perspective at a time (*i.e.*, single-perspective case) in [8]. The real-life problem is that a single-perspective cannot typically accommodate all the data available in a hologram. Therefore, to get the full picture, one needs to have the possibility of changing the reconstructed perspectives on-the-fly. In the paper we introduce an intuitive user interface, which is intended to solve this challenge and give a user full control over the display of holograms while using the conventional 3D displays. This novel and intuitive solution utilises inter-cognitive communication, *i.e.* information transfer between two cognitive beings with very different cognitive capabilities (in our case – a human user perceiving a holographic image and a machine making the 3D

reconstruction of the digital hologram) according to definition by Baranyi and Csapo [9].

## II. USER INTERFACES FOR 3D DISPLAYS

Over the recent years multiple novel user interfaces (UIs) were suggested for controlling 3D data display and interaction with 3D data.

In [10] the authors evaluated the conventional human-computer interfaces (*i.e.* mouse and keyboard) and the trackball-based 3D navigation and manipulation desktop devices, such as SpaceTraveller and Globefish in bi-manual configuration. The presented results reveal that use of a special 3D manipulation device in non-dominant hand enables one to reduce the time required for different operations with 3D objects.

A large group of applications use for controlling 3D data display the UIs, which are based on inertial motion sensing. These interfaces are typically implemented as a device, which a user holds in his hand and which has a set of buttons and sensors for capturing the gestures of a user. The sensed data can be sent to a computer either over wires (see, *e.g.*, [11]) or through a wireless interface (*e.g.*, Nintendo Wii Remote or PlayStation Move controllers, see [12-13]). In some applications, instead of a special device is used a smartphone (see, *e.g.*, [14-15]).

The recent advances in the computer vision and the introduction of Microsoft Kinect system boosted the development of contactless gesture-based UIs. Those interfaces were used *e.g.*, in [16] to distinct ten different hand gesture commands or in [17] to detect how many fingers the user was raising. Han *et al.* [18] provided a review study of Kinect based computer vision systems including hand gesture analysis. Nonetheless, as shown *e.g.*, in [17-18], the vision systems have limitations concerning accuracy and reliability of hand gesture detection. Besides, for efficient operation these systems require a user to keep his hands close to camera in the plane parallel to the one of the camera sensor.

Compared to computer vision based interfaces, the glove based systems allow more precise hand and finger orientation accuracy and do not have serious limitations about user's mobility or hand positions. The major drawbacks of the glove-based user interfaces are that those might cause some discomfort and hinder the naturalness of the user's hand gestures [17]. The early versions of data gloves [19] detected only the finger touches and transferred the data over wired interfaces. The more recent examples, *e.g.*, [20-22] use the wireless connection to the computer. The solution reported by [20] used the ZigBee radio connection and the Ink-Jet based printed sensors to detect finger bend and finger pressure. The robust gloves in [21] used metallic fabric pads and conductive thread to detect finger presses and Bluetooth radio communication. The glove design was leveraged via a visual motion tracking camera mounted on the helmet. The solution in [22] used Bluetooth connection and the Bi-Flex sensor,

which changes resistance when bent, to capture the movements of each individual finger.

Considering the 3D nature of holographic data and our previous experience with 3D UIs, we decided that the most suitable way of controlling hologram reconstruction parameters is based on the hand gesture recognition. To enable this, we have designed and implemented a novel glove-based interface with integrated Wireless Sensor Network (WSN) node and a minimum set of simple sensors.

### III. WIRELESS SENSOR GLOVE INTERFACE

The interface is implemented as a glove with a WSN node attached (see Fig. 2). The node is built around Texas Instruments (TI) eZ430-RF2500 printed circuit board (PCB), which contains an MSP430 microcontroller and a CC2500 radio module. In order to enable gesture capturing, we attached to the main PCB a PCB with accelerometer and gyroscope. To control the position of the fingers, we also added the Infrared (IR) emitter on the fingertip of thumb and two IR detectors on the fingertips of index and middle fingers. The node is powered by a single CR2032 lithium battery.

The state diagram of sensor node microcontroller's operation is depicted in Fig. 3. Once the node is powered, microcontroller initialises all the used components and starts periodic measurements. Before each measurement, the microcontroller firstly checks the available supply voltage. After this, a reference measurement of the background IR light intensity is done. Note that during this measurement the IR emitter on thumb is off. Then the microcontroller turns on the IR emitter and makes another measurement. Finally, the microcontroller reads the data from accelerometer and gyroscope. All these data are packed in a single 24-byte packet, which also contains the unique 1-byte addresses of the glove and the dongle. Also, each packet contains a checksum which is used to ensure data integrity. Once the packet is ready, the microcontroller forwards it to the radio and switches to low-power sleep mode.

The radio module uses minimum-shift keying (MSK) and operates in the license-free 2.4 GHz industrial, scientific and medical (ISM) radio band. The data are transferred with the over-the-air data rate of 250 kbit/s. Considering the specifics of the application, each packet is sent only once and we do not use any mechanism to control the delivery.

The default period between the measurements is 33 ms. Nonetheless, the measurement period, as well as the used radio channel and the addresses of a glove and a dongle, can be modified. For this, one needs to connect the PCB on the glove to a PC using a USB dongle and issue the special commands from terminal software.

The USB dongle receives the packets, checks data integrity and forwards the valid packets to the PC using the serial-over-USB interface. All the processing of the received data is done solely by the PC software application.

The graphical user interface and processing software are implemented on the Matlab environment. The holograms are reconstructed with a parallel processing by using CUDA. The

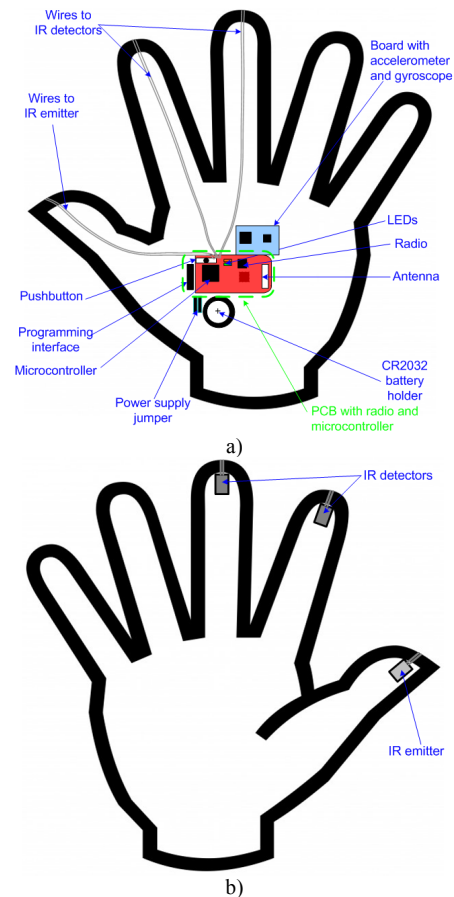


Fig.2. WSN glove interface  
a) back side b) palm side

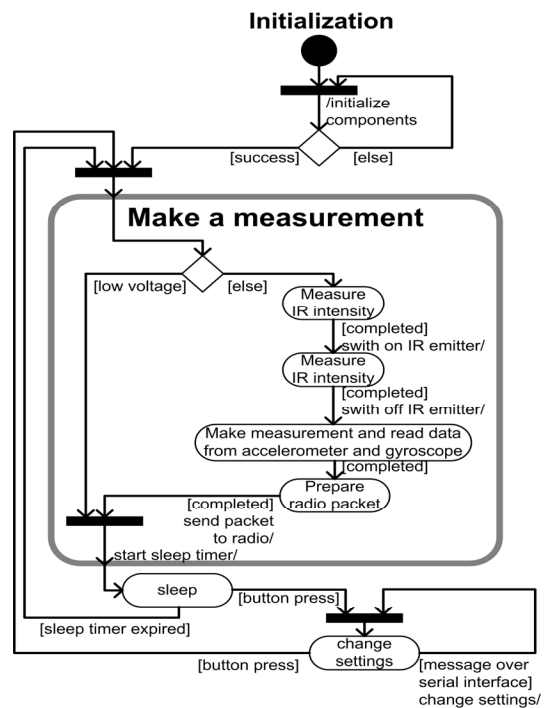


Fig.3. State diagram for WSN glove node

software is calibrated at the beginning as the ranges of hand

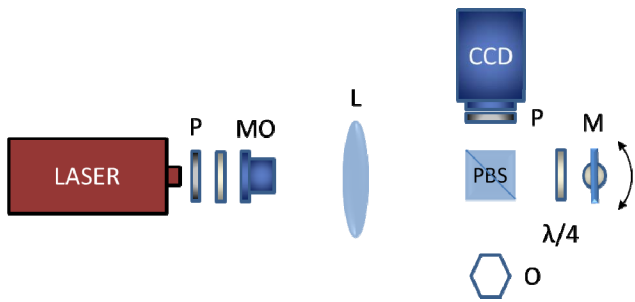
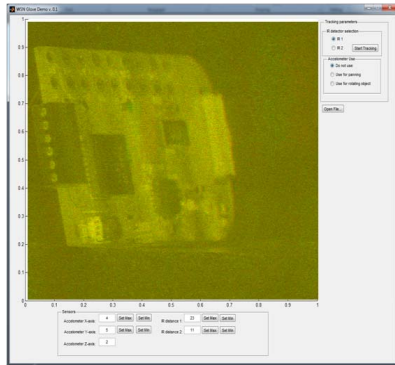


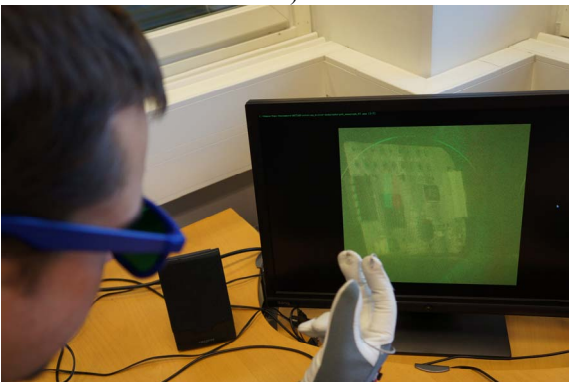
Fig.4. Experimental setup for hologram capturing based on Michelson interferometer (P=polariser, MO=microscope objective, L=lens, PBS=polarizing beam splitter,  $\lambda/4$ =quarter waveplate, M=mirror, O=object, CCD = CCD camera with 1024x1024 pixels and 5.5  $\mu\text{m}$  pixel pitch)



a)



b)



c)

Fig.5. Photos, made during the testing of WSN glove interface a) UI of the SW application during calibration b) and c) test-person using the interface to control hologram reconstruction parameters (note the different reconstruction focus distance and perspective of reconstructions depicted in b) and c))

and finger motions are different for each individual. The calibration procedure of an accelerometer requires a user to roll his/her palm at two extremes, the calibration of IR emitter and receiver requires a user to move his thumb and index fingers close to and far from each other. The range of available perspectives and range of meaningful reconstruction distances are scaled to the calibration data.

After the calibration, the WSN glove interface is ready to control the hologram reconstruction parameters. For using the system, a user should imagine that he/she holds the displayed object using thumb, index and middle fingers and that the actions with this imaginary object will be mirrored on the displayed hologram. The received from the glove sensor values are used in the hologram reconstruction process. The data about user fingers' positions are used to specify the reconstruction depth and the hand roll position is used to control the displayed perspective. Two reconstructions are used to form a red-green anaglyph which is displayed to the user wearing colour coded lenses. More detailed procedure how to form an anaglyph from a digital hologram is described in [8]. In order to compensate for possible background IR interference, the results of the reference IR measurement are subtracted from the results of the actual IR measurement.

#### IV. EXPERIMENTATION

In order to understand capabilities and limitations of the developed user interface and its feasibility for displaying holographic data, we conducted a set of the real-life experiments. For these experiments we captured digital holograms of real world industrially manufactured 3D objects by using the set-up depicted in Fig. 4. The parameters for the computed and displayed hologram reconstructions were obtained from the developed WSN glove interface. The reconstructions were displayed on a conventional 3D display based on anaglyphic technique (see Fig. 5).

The developed interface proved itself rather well and it took a test person only few minutes to get used to working with it. The only weakness of the interface was the limited angle of view of the used IR detectors (only 30°), which sometimes caused difficulties while specifying the focus distance. Nonetheless, in future we will consider replacing the IR detectors with the ones with wider field of view.

#### V. DISCUSSION AND CONCLUSIONS

In this paper we have introduced and discussed in details the novel method to interact with a conventional 3D display and to control the reconstruction parameters of holographic data. To the best of our knowledge the suggested interface is the first, which is targeted specifically for controlling the reconstruction parameters of holographic data together with conventional 3D displays. The suggested user interface is based on Wireless Sensor and Actuator Network (WSAN) technology and is implemented as a glove with a set of proximity sensors, an accelerometer and a gyroscope mounted on a glove. The sensed data about the position of user's hand and the relative positions of fingers are streamed over the radio link and input into the software application, which controls reconstruction parameters of the holograms. The

reconstruction distance and the perspective of the digital hologram are changed based on the user's gestures.

Compared to the existing 3D user interfaces, the suggested one provides much simpler and cheaper solution. Unlike the computer-vision based techniques, the suggested interface does not require cameras, needs much lower computing power and enables the mobility of the users.

In order to evaluate the suggested interface, we have captured few holograms of the industrially manufactured 3D objects (see Fig. 1). The holograms were reconstructed and displayed on a conventional 3D display based on anaglyphic technique. The hologram reconstruction parameters were controlled by the user's gestures, which were captured by the developed WSN glove interface. The interface proved itself rather good, although it was noted that minor updates can improve the performance of the interface.

We are convinced that the digital holography technique will find wide application area in different fields. Among the most promising fields for applying this technology are industrial applications. There, the digital holography can be used for quality control and enable detection and analysis of possible defects. When applied to microscopy, the holography can be used for high resolution analysis of raw materials used in production and of engineered surfaces of high-precision components [23].

The use of the suggested WSN-based user interface in the industrial environment might also have additional value. Thus, the CogInfoCom-aided manufacturing based on the WSN control interface for robots would provide more freedom of mobility and orientation for the user compared with computer vision gesture control solutions, e.g., [24]. In such a case, the developed solution might be combined with the solution suggested in [25]. This will introduce the novel tactile feedback channels which might enhance the user experience and enable more efficient object perception. Besides, the suggested user interface can be extended to support for other features available from the WSN technology which might be useful in industrial scenario, e.g.:

- localisation of the users and mobility control [26–28],
- transmission of emergency and alarm messages to/from the users [29,30],
- industrial process monitoring [31],
- control of worker's safety and access rights [32].

Although in the current work we have used the developed interface only for controlling the reconstruction parameters, in future the system can be extended also to control the parameters of the physical hologram capturing set up. This can be done by placing an object on a rotation stage which is controlled by the gestures of the user. In this way the object can be rotated and a new hologram can be captured if the user wants to see a perspective which is not available in the current hologram.

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