Simulation aided design of a human wrist rotation recognition system combining IMU sensor data with Visible Light Communication

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***Abstract*—Wrist worn mobile sensors have proven to be applicable for various applications, including fitness tracking or gesture recognition. In time- and security-critical application scenarios, the commonly used Radio frequency based communication technologies may pose a bottleneck for further advancements. In this work, we present a simulation environment implemented in Matlab/Simulink that enables the precise simulation of wristbands that are equipped with light emitting diodes, which take over the task of data transfer by means of visible light communication in a fast and secure way.**

Keywords—visible light communication, gesture recognition, IMU data

I. Introduction

The widespread use of wrist worn mobile sensors in smartwatches or fitness monitoring devices has led to an ever-increasing number of applications such as activity tracking or health monitoring. In [1] it is shown that off the shelf smartwatches can accomplish the task of motion tracking with similar accuracies as research grade sensors and systems. These results demonstrate that the approach of wrist worn sensors has become a feasible way of human activity recognition. The sensor technology used in such wrist worn devices are strongly correlated to the activity that should be recognized or the data that should be acquired (e.g. heartrate) [2]. In applications where gestures of the wrist or the hand should be recognized [3,4], inertial measurement units (IMU), usually consisting of a 3-axis accelerometer, a 3-axis gyroscope and a 3-axis magnetometer, are prevalently used. With the predominant focus of the usage of such sensors for monitoring and tracking, the aspect of how the data are transferred to a receiver (e.g. smartphone) is often underrated. In most systems, standard Radio Frequency (RF) based interfaces (e.g. Wi-Fi, Bluetooth, etc.) are used. Issues like delay time, stability of the data transfer as well as the setup time of the communication (e.g. Pairing phase in Bluetooth communication) can be ignored in applications where the data are only logged and analyzed in an offline mode. When wrist worn sensors are used to perform time critical control or steering functionalities, the aforementioned issues highly influence the feasibility of such systems. In [3] a system is discussed, in which the evaluation of IMU data in comparison with optical motion capture data of guitar strumming gestures is done. The two major deductions from this work are that on the one hand the IMU data are a good approach to recognize such complex gestures but on the other hand that the jitter and the restricted bandwidth of the used Bluetooth Low Energy (BLE) communication interface are some of the major drawbacks. Also the work in [4] reports delay times in the range of ~200ms utilizing Bluetooth. Furthermore, in envisioned applications of, for example, real-time control of surgical robots by wrist rotation also the security aspects of spamming or spoofing must be taken into consideration.

Visible Light Communication (VLC) is a communication technology where by modulating the intensity of an artificial light source(s) (usually a Light Emitting Diode (LED)) and demodulation at a photosensitive device (usually a photodiode (PD)) data are transferred. With this approach, several of the issues of RF communication can be overcome [5]. VLC is also able to provide high bandwidths and is immune to interference in the RF spectrum. Furthermore, since light, unlike RF waves, is not penetrating through walls, security concerns in regard of spoofing or spamming are not an issue. Especially in the aforementioned potential application of controlling a surgical robot by the means of wrist rotation, the usage of RF based communication is largely forbidden in sensitive areas like surgery or emergency rooms. Therefore, VLC based transmission of data from a wrist worn to a receiving device has the potential to enable highly time- and stability- critical applications.

In this work we will show the simulation aided design of a wristband that is equipped with LEDs to transmit data between the wrist worn device and a receiver placed in the infrastructure (ceiling) of the room. The design of a wristband that guarantees a continuous and stable communication with the receiver is a complex task. Many factors such as the overall geometry of the room, geometry of the wristband, the position of the wristband in relation to the receiver, as well as the characteristics of the utilized LEDs (output power, spectral composition of the emitted light, radiation angles etc.) and the parameters of the receiver (Field of View (FoV) of the PD, Angular sensitivity of the PD, spectral sensitivity of the PD etc.) must be taken into account. In our self-developed simulation environment, implemented in Matlab/Simulink, these parameters are integrated in the most flexible way, in order to enable the design of such an innovative communication interface for wrist worn devices.

II. System model

In order to design a proper VLC based wristband our simulation environment fulfills the necessity of a comprehensive integration of all the characteristics of the electronic components, as well as the geometrical implications. It is imperative that the designed wristband guarantees continuous communication and therefore it must

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be ensured that for (almost) all the applicable positions in the room and for any rotation angle of the wristband a certain intensity of light emitted from the LED(s) on the wristband is received at the photodiode and consequently a voltage signal value larger than a certain threshold value is induced in the receiver. Figure 1 shows a sketch of the envisioned novel communication system

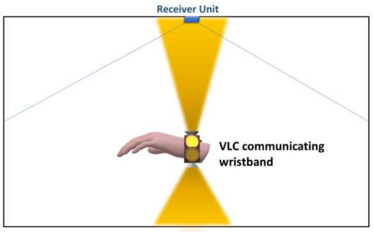

Fig. 1. Illustration of the application of a VLC communicating wristband

The related channel model is based on the work done in [6] and has been extended and improved to fulfill the complex task of a precise simulation of the VLC communicating wristband. Especially the angle dependent parameters of both the LED(s) and the PD are amongst the most decisive in the design, since for example the achievable output current of the PD is strongly influenced by the angle of incidence of the light on the PD. In the system model these characteristics alongside the output power of the LED and the spectral composition of the emitted light, can either be taken from the datasheets of the respective components or can be experimentally determined values. Additionally, we also incorporate characteristics of the necessary Transimpedance Amplifier connected to the PD in our system model.

III. System model Comparison to Experimental Data

In the following, we show the good agreement between our simulation results and real world measurements on the base of a direct comparison of suchlike simulated output signals of the receiver to real world experiments in a small scale setup.

IV. Wristband

Based on the established system model, one can take advantage of a simulation aided design of different VLC communicating wristbands. By varying the constraints such as the type of LED, radiation characteristic of the LED etc., one can furthermore outline the influence of different parameters. As an example, in the following we discuss the simulation of a wristband equiped with 4 LEDs and the corresponding normalized output values of a receiver placed on the ceiling, when the wristband is rotated at a certain position in the room. Figure 2, upper illustration, shows the wristband with the 4 LEDs mounted in an equally spaced arrangement on the circular shaped wristband at a certain position in the room. For better visualization the wristband is depicted in a much larger scale. The diameter of the wristband has been set to 5.88 cm. Figure 2, lower plot, shows the output of the receiver circuitry when this wristband is rotated 360° in a counterclockwise direction. The condition of the wristband as depicted in Figure 2 (upper illustration) is considered to be 0° rotation.

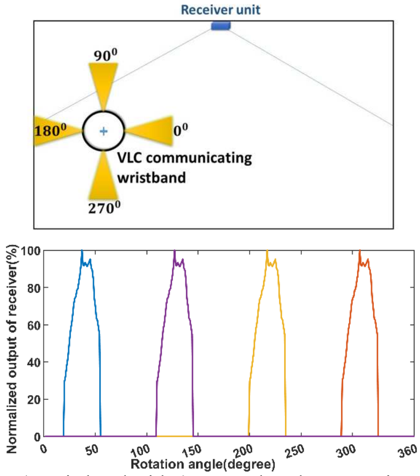

Fig. 2. (upper) Wristband with 4 LEDs placed at a certain position in an exemplary room (lower) normalized output voltage of the receiver for a rotation of 360°.

Figure 2, lower plot, shows that this design of a wristband is not fulfilling the main criteria, that for every possible rotation of the wristband data transmission is possible, since for example at a rotation of 100° no light from the LEDs is impinging on the receiver. Therefore, in this specific example one can infer that more LEDs (or with other radiation characteristics) have to be placed on the wristband. This example illustrates how the simulation environment can be used to design and optimize such wristbands using VLC for the transmission of IMU data. Furthermore, the simulations can be used to optimize the design in regard of certain other relevant parameters, such as energy consumption, number of necessary components etc.

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