Remote Mobile Patient Monitoring using Diffuse Optical Transmissions

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Abstract: In the context of remote patient monitoring, we propose in this paper a radio free solution based system to transmit health related data. We investigate wireless optical technology based on diffuse infrared links, which presents the advantage to be secure regarding electromagnetic interference, low-cost and easy to deploy. Two different monitoring scenarios are considered, both composed of an emitter worn by a mobile patient and receivers fixed in the environment. The first scenario is the continuous remote monitoring of heart rate and temperature and the second one involves accelerometer data. To evaluate the wireless mobile link reliability for the two scenarios, we have developed custom made systems using commercially available components. The experimental performance is established in terms of packet loss to evaluate the potentiality of wireless optical technology.

1 INTRODUCTION

Nowadays, there is a rapid growth in medical devices that incorporate wireless Radio-Frequency (RF) technology. By eliminating the cables restricting patient mobility during stay in hospital, wireless devices contribute to improve patient health outcomes. However, because of an increasingly crowded RF environment, the risk of electromagnetic interferences with other medical devices has to be considered (Periyasam, 2013). In addition, the question of prospective health effects of RF signals in particular long exposure impact is still open (Benson, 2013). Thus, the deployment of RF devices can be risky and thus limited in sensible environments such as hospitals or healthcare organizations, where high data security and high immunity against interference with other existing RF and electronic devices are required.

To overcome this limitation, Wireless Optical Communication (WOC) based systems can be used as alternative or complement to RF ones for wireless monitoring in hospitals (Torkestani, 2012). This technology has the potential of reducing the amount of RF effects in patient vicinity because WOC wavelength range ensures that there is no interference with existing RF and electronic equipment. In addition, WOC systems have many advantages over RF ones such as being free of license, compact, low cost and having a great level of security because light cannot pass through walls.

Communicate by using optical beams is one of the oldest solutions. Since (Gfeller, 1979) WOC in infrared range have been standardized and with the development and maturity of optoelectronic devices, this technology has experiencing a renewed interest. Indeed, for many years, systems based on infrared or visible wavelength range have been studied for indoor and outdoor applications (Carruthers, 1997, Elgala, 2011; Arnon, 2012; Borah, 2012; Ghassemloy, 2013).

Two main link configurations are commonly investigated: Line of Sight (LOS) scheme and diffuse one. In LOS configuration, the transmitter is directly pointed towards the receiver. This scheme is easy to implement and offers high performance, but it is highly sensitive to misalignments and blocking effects. Diffuse schemes are more robust because they exploit multiple reflections of optical beams over the surface environment to establish non-directed links between emitter and receiver. The potentialities of using WOC for healthcare monitoring have been already investigated (Torkestani, 2011; Torkestani, 2012; Noonpakdee, 2013). In our previous works the theoretical performance has been established by determining

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link outage probability for both LOS and diffuse systems considering emitter mobility.

In this paper, we investigate the feasibility of practical WOC based system using diffuse optical transmissions to remotely monitor health data. We have developed a custom made system dedicated to a realistic monitoring scenario in a medical unit of Limoges University Hospital Center (CHU) concerning post-stroke patients. The objective is to remotely transmit physiological and physical activity data during the first weeks of rehabilitation and re-training effort, which is a critical phase for patients. During this phase, the patients move in a life experimental set up of Physical Medicine and Rehabilitation unit of Limoges hospital. They are placed in a real situation to assess their capacity to exercise in different situations of everyday life such as getting out of bed or cooking for example. It is therefore extremely important to monitor the patient throughout this phase and to take into account patient mobility.

In such context, our contribution in this paper concerns the experimental evaluation of the wireless optical technology to transmit health data between an emitter worn by a mobile patient and receivers fixed in the environment. We investigate two different monitoring scenarios, the first one is the continuous remote monitoring of heart rate and temperature and the second one involves accelerometer data.

2 SYSTEM DESCRIPTION

The experiments are performed in a test room of dimension (6.6m x 6.7m x 3m) as shown in figure 1. Black areas in the figure correspond to elements of the furniture. Scratched area corresponds to a window placed over the entire length of the wall.

In this environment, we consider a patient equipped with sensors connected to a wearable hardware unit attached on the body and communicating by using an optical source which is an eye safe Infrared (IR) Light Emission Diode (LED).

Data are sent using Intensity Modulation and Direct Detection (IM/DD). Four receivers composed of photo-detectors (named A to D on figure 1) are fixed on the ceiling and oriented towards the floor.

They are connected to a distant computer allowing remote access to the data. In such configuration, because of patient mobility and source position on patient body, the communication link is mainly a Non – LOS one, established by exploiting diffuse reflections over the environment. A receiver collects beams from all the reflective surfaces, and thus the total received power is the sum of all reflective room elements contributions.

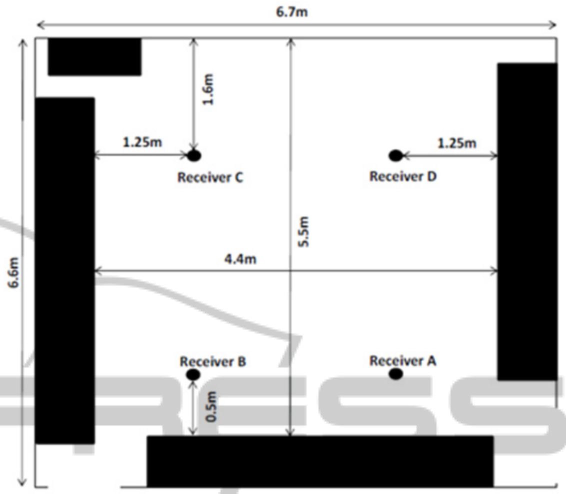

Figure 1: Indoor test environment.

2.1 Transmitter

The optical source is a high power infrared diode (TSAL5100) emitting around 940nm, having a half-power angle of 10° and generating a maximal optical intensity of 130 mW/sr.

In the first scenario, we have designed a jacket worn by the patient equipped with two sensors: a chest belt for cardiac frequency and a thermistor as temperature sensor, located under the arm. The LED is inserted in a plastic part and located on the jacket shoulder by snaps (figure 2). A cable connection is realized between the LED and a control unit. In this configuration, the optical source is mainly oriented towards the ceiling but it may also point to the walls and obstacles in the environment according to body movements.

For the second scenario, the wearable device is composed of tri-axial accelerometer (MMA7631LC) and attached on the patient arm (figure 3). The optical source is mainly oriented towards the ceiling as in scenario 1, but the orientation can be also varying according to arm movements.

In both scenarios, the control unit of the device is composed of a microcontroller based on Atmega328, battery pack and electronic LED driver. The signal is emitted with an On-Off Keying (OOK) modulation, at a baud rate of 4.8 kbps and with a subcarrier at 38 kbps.

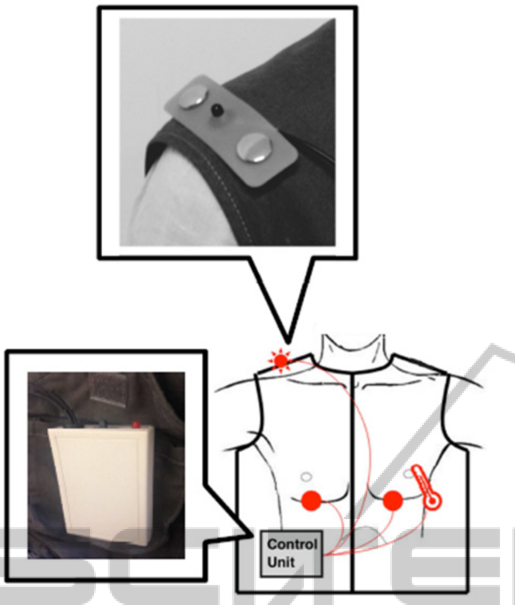

Figure 2: Wearable device for scenario 1 (cardiac frequency and temperature).

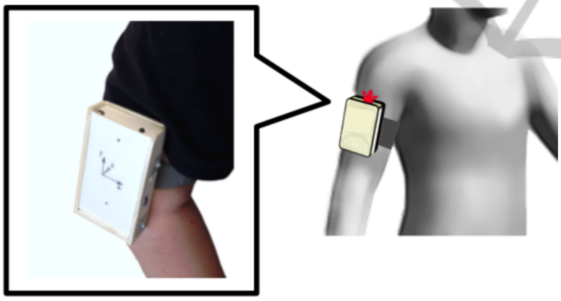

Figure 3: Wearable device for scenario 2 (accelerometer data).

2.2 Receiver

The receivers consist of infrared modules composed of photo-detectors and preamplifiers (TSOP34338) with FOV of 45° and a minimal irradiance of 100µW/m². They are located in the corner of the false ceiling tiles with a plastic part to ensure that they are pointing towards the floor (see figure 4).

Moreover, they are arranged uniformly on the ceiling as presented in figure 1. They are all powered by Ethernet modules and connected to a switch transmitting the received data to a remote computer connected to a standard RJ45. The computer analyses the received data and fills a table containing the sensor information so that it can be exported at the end of the measurement, and then plots the measured parameters on a scrolling graph as data arrive.

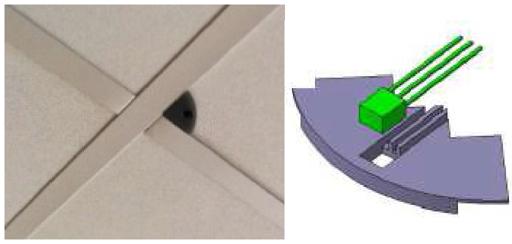

Figure 4: Optical receiver module.

2.3 Data Packets

The two types of health data are transmitted, following a common scheme represented in figure 5. In both cases, we consider a frame delimiter, a patient identifier (4 digits: $P_3P_2P_1P_0$), a verification code obtained by summation of information data (9 digits: $V_8V_7V_6V_5V_4V_3V_2V_1V_0$) and a measure increment (3 digits: $I_2I_1I_0$) to identify the information once when it is received from different receivers. The verification data and the redundant transmission of patient identifier are two different ways to check the integrity of the data.

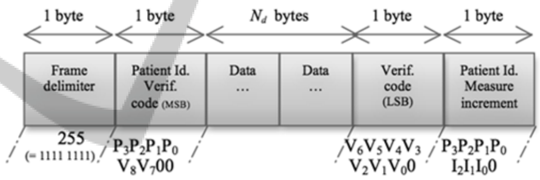

Figure 5: Packet description.

Depending on the scenario, data packets are not transmitted at the same period. Let's denote T_e this time duration. In addition, the packet duration T_p depends also on the scenario as presented in the following. According to the value of T_p / T_e ratio, the maximal forward current through the photodiode is not the same. In each scenario, we adjust the emission circuit so that we maximize the current and thus the resulting emitted power.

For the cardiac frequency plus temperature transmission, data are transmitted at the rhythm of heart rate, so T_e is of the order of the second. The information data are carried over $N_d = 2$ bytes and the verification code is obtained by summation of temperature, cardiac frequency, patient identifier and measure increment. This scheme leads to $T_p \approx 10$ ms so that T_p / T_e is of the order of 1%. In this case the forward current is fixed to 325mA. Considering the temporal occupancy, the average emitted power is less than 0.5 mW.

For the accelerometer data transmission, there are $N_d = 6$ bytes containing accelerometer values over the three dimensions (x, y, z) from the 10-bits analog to digital converter. The verification code is in this case obtained by summation of the first five MSB of accelerometer data over the three axes, patient identifier and measure increment. This scheme leads to $T_p \approx 20$ ms. In addition, data are transmitted each 0,1s so that T_p / T_e is around 20%. The forward current in this case is fixed to 150 mA, and the average emitted power is less than 4 mW.

3 EXPERIMENTAL RESULTS

To evaluate the wireless optical technology performance, we have measured packet loss during mobile transmission within the room presented in figure 1, for the two scenarios previously described.

We have performed several measurements with different persons equipped with the two kinds of devices and different conditions of lighting from sun and neon lights at room ceiling. Moreover, during the test, persons moved regularly throughout the environment.

A packet can be lost for two reasons: the signal is not received or it is bad received. The signal is not received if its amplitude is too low to be detected by the photo-detector, for example when an obstacle blocks the optical beam. A packet is bad received when it contains an error so that the receiver rejects it. An error is detected as soon as the redundant patient identifier or the verification code is wrong.

Performance is presented in terms of packet loss rate determined by the number of lost packets over the total number of packets sent.

We have evaluated the transmission performance for one active receiver, two and four. The obtained results are reported on table I, averaged from 10 measurements for each scenario. The measurements were carried out over a period of 30 min in order to detect at least 10 packet losses which are necessary to have reliable paquet loss rate information. For one active receiver, measures have been performed for each receiver A to D. For the case with two receivers we have considered the couples A-C and B-D corresponding to room diagonals.

As expected, we can see that the performance improves when the number of receivers increases.

When there are only one or two receivers, scenario 2 leads significantly to more packet losses than scenario 1. This can be explained by the fact that due to the higher ratio T_p / T_e in scenario 2, the forward current in the photodiode is lower than in scenario 1, which means a lower peak optical emitted power. In addition, the emitter position is not the same on the patient body so that the body can be more blocking in scenario 2.

Table 1: Packet Loss Rate.

Number of receivers	*Scenario 1*	*Scenario 2*
4	$1{,}3.10^{-3}$	$1{,}3.10^{-3}$
2	4.10^{-3}	$1{,}5.10^{-2}$
1	4.10^{-2}	0,11

When the number of receivers increases, we first remark for scenario 2 that the performance is significantly enhanced. Indeed, the packet loss rate has been improved by one decade by comparing the results obtained from 1 to 2 receivers and also from 2 to 4. On the other hand, we can note that for scenario 1 this improvement is not so important: the packet loss rate from 2 to 4 receivers is only divided by 3. In addition it can be noticed that with 4 receivers, performance between both scenarios tends towards a similar value. These observations can be explained by the fact that, in scenario 1, as the peak optical emitted power is larger, the optimal room coverage is achieved with fewer receivers than in scenario 2.

Finally, our experimental results show that it is important to take into account the data packet parameters in order to deploy the right number of receivers allowing a given quality of service in terms of packet loss while optimizing the emitted power.

Besides, we can say that the value obtained with 4 receivers, which is 10^{-3}, is a typical one in wireless transmission system and permits concluding that the wireless optical transmission reliability is ensured.

4 CONCLUSIONS

In this paper, we have presented the experimental performance of an alternative solution to radio frequencies for healthcare mobile monitoring that is wireless optical technology. We have used as a criterion the packet loss of the transmitted data for two health-related monitoring scenarios having different constraints.

For both scenarios, we have investigated the wireless data transmission between a mobile emitter worn by the patient and receivers fixed in the environment, by exploiting optical diffuse reflections over the room surfaces.

The measurement results obtained with two prototypes made of commercially available and low cost components have shown that the optical wireless technology constitutes a reliable solution for health monitoring. In the best coverage configuration, a packet loss of 10^{-3} has been obtained for both scenarios.

Future work will consist in conducting this experimentation in the life experimental unit of Limoges hospital and to evaluate the reliability in real context of use, especially considering several monitored patients. In addition, one important point is to enhance the system by reducing the consumption and to work on its miniaturization.

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REFERENCES

Arnon, S., Barry, J., Karagiannidis, G., Schober, R., and Uysal,M., 2012, *Advanced Optical Wireless Communication Systems*, Cambridge University Press.

Benson, V. S., K. Pirie, et al., 2013, 'Mobile phone use and risk of brain neoplasms and other cancers: Prospective study', in *International Journal of Epidemiology* 42(3): 792-802.

Borah, K., Boucouvalas, A.C.,Davis, C.C, Hranilovic, S., Yiannopoulos, K., 2012 'A review of communication-oriented optical wireless systems' in *EURASIP Journal on Wireless Communications and Networking*, 2012:91.

Carruthers, J.B., Kahn, J.M., 1997 'Modeling of nondirected wireless Infrared channels' in *IEEE Transaction on Communication,* 45, 1260–1268.

Elgala, H., Mesleh, R. and Haas, H., 2011, 'Indoor optical wireless communication: potential and state-of-the-art', in *Communications Magazine, IEEE*, vol. 49, no. 9, pp. 56-62.

Gfeller, F.R.; Bapst, U., 1979, 'Wireless in-house data communication via diffuse infrared radiation', *in Proc. of the IEEE*, vol.67 ,no.11, pp.1474,1486.

Ghassemloy, Z., Popoola, W., Rajbhandari, S., 2013, *Optical wireless communications, system and channel modeling with MATLAB®*, CRC Press.

Noonpakdee, W., 2013, 'Adaptive wireless optical transmission scheme for health monitoring system' in *Consumer Electronics Berlin (ICCE-Berlin) IEEE Third International Conference on*, pp.161,164.

Periyasam, M.; Dhanasekaran, R., 2013, 'Electromagnetic interference on critical medical equipments by RF devices', in *Communications and Signal Processing (ICCSP), International Conference on*, pp.78-82.

Torkestani, S. S.; Barbot, N.; Sahuguede, S.; Julien-Vergonjanne, A; Cances, J-P, 2011, 'Performance and transmission power bound analysis for optical wireless based mobile healthcare applications', in *Personal Indoor and Mobile Radio Communications (PIMRC), 2011* IEEE *22nd International Symposium on* , pp.2198,2202.

Torkestani, S.S.; Sahuguede, S.; Julien-Vergonjanne, A; Cances, J.P., 2012, 'Indoor optical wireless system dedicated to healthcare application in a hospital' in *Communications, IET* , vol.6, no.5, pp.541,547.