Ultra Wide Band Integrated Optical-and-Digital Approach for Smart Factory

Host Research Unit: *Lab-STICC, CNRS UMR 6285*

Host Institutions: *Université de Bretagne Occidentale (Brest, France)*
Ecole Nationale d'Ingénieurs de Brest (ENIB), Brest, France

Partner Institution: *Memorial University, Canada*

Supervisors: *Emanuel RADOI, Stéphane AZOU, Roua YOUSSEF*

Starting date: *October 2019*

Funding: *around 1684 € gross/month*

Context and aims

Short-range wireless communications have known considerable growth over the last few years, especially due to the increasing and widespread deployment of various types of wireless networks (WLAN/ WPAN/WBAN). Moreover, the emergence of the Internet of Things (IoT) and smart factories (Industry 4.0) makes this type of communications unavoidable in the years to come. The related applications are often associated with needs in terms of high data rate communication (HDRC) and accurate indoor localization and tracking (AILT), whereas traditional access to spectral resources becomes increasingly difficult, given the congestion of the RF spectrum.

To handle this bottleneck, we consider in this Ph.D. thesis an Impulse Radio Ultra-Wide Band (IR-UWB) approach [1], characterized by the emission of extremely short pulses with a very low-power level and no harmful effect on the human body. It is thus possible to use a large part of the radio spectrum without disturbing the licensed narrowband systems that operate in different frequency bands [2]. Other benefits of this approach are its robustness in a harsh environment, high precision ranging, low power consumption and high penetration capabilities.

The research we have carried out so far, mainly in the framework of 4 doctoral theses ([3]-[6]), has resulted in various contributions on the blind estimation of the IR-UWB signal parameters [7], UWB over fiber (UWBoF) transmission systems employing semiconductor optical amplifiers ([8]-[10]), and accurate indoor localization [11, 12]. We have also proposed signal processing algorithms for intelligent IR-UWB systems that can adapt to the environment by waveform adaptive design, channel estimation and automatic receiver reconfiguration ([13]-[15]). We have recently shown [16, 17] that the theory of compressed sensing [18] allows reducing the cost, complexity and energy consumption of coherent IR-UWB receivers, thus making them accessible to most applications [19], which can benefit from their optimal performance.

However, the huge instantaneous frequency band to be processed also leads to strong constraints, beyond the specifications of the state-of-the-art digital circuits (e.g., analog-to-digital conversion). The proposed research will deal with these challenging aspects, by taking advantage of the capabilities and complementary aspects of both wireless IR-UWB and UWBoF technologies [20, 21]. Relevant approaches include, but are not limited to, compressive sensing, modulated wideband converter, optical ADC, signals with finite rate of innovation, multichannel modulating waveform schemes, and sub-Nyquist sampling.

From an applicative point of view, the research developed in the framework of this Ph.D. thesis aims at increasing the safety and the security in smart factory-like indoor environments. The proposed UWB signal processing algorithms will provide high data rates, as well as accurate indoor localization and tracking, and will rely on an integrated optical-and-digital architecture (IODA). Thus, instead of connecting the UWB transceivers to the central station through RF cables or wireless, which are lossy, bandwidth-limited, and sensitive to the electromagnetic interference, we will investigate the UWBoF transmission between central stations and distant antennas. This approach enables centralized signal processing and is able to solve the synchronization problems occurring in conventional UWB localization systems.

The research work will firstly focus on the optimal design of the UWB waveform, so as to maximize its spectral efficiency, under some constraints (e.g., spectral masks and orthogonality), as well as on the associated signal processing algorithms, in an attempt to jointly achieve HDRC and AILT, with green low cost IR-UWB sensors, suitable for the targeted application mentioned above. Compared to recently reported results [22], a specific work will be done on pre-distortion schemes for the optimized waveforms, to compensate nonlinear effects inherent to UWBoF transmission. Then, the sampling rate for the digital signal processing will be significantly reduced, under the Nyquist limit, by using the sparse representation of the received signal and recent compressed sensing results [23].

Another important objective of this Ph.D. thesis will be to develop a robust technique for the UWB-based multi-humans detection in a smart factory-like indoor environment. Indeed, despite the improvements achieved by some recently proposed CFAR (Constant False Alarm Rate) algorithms [24], the multi-humans detection cannot be considered yet as being completely reliable, since it is often flawed by multiple false alarms due to the multipath components and the background clutter. Another related issue is the discrimination of humans from other moving objects, which is also important for the considered application. We aim to associate this function to the UWB-based detection, localization, and tracking, and improve its accuracy by extending the feature set considered so far (maximum magnitude, velocity and RMS range spread) with new salient features. As the IR-UWB localization system is tag-less, the localization of equidistant/nearly located people and non-line of sight (NLOS) objects cannot be accurately performed using conventional algorithms. To solve these issues, deep learning coupled to a large database of appropriately defined feature set will be investigated.

The work planned for this Ph.D. will be jointly carried out within the research teams COM and DIM of Lab-STICC CNRS UMR 6285, which will provide all the supervision skills, as well as the required computing facilities and measurement equipment. In order to handle both the digital and optical aspects of the thesis and to develop and test the new UWB processing techniques, the Ph.D. student will be granted access to the UWB and Industry 4.0 platforms, located at UBO, as well as to the UWBoF equipment, located at ENIB. The UWB platform consists of an arbitrary waveform generator, an UWB vector signal generator, UWB antennas, and a high performance digital oscilloscope. The Industry 4.0 platform is a smart factory-like SCADA production chain, integrating different cybersecurity control mechanisms. The UWBoF equipment includes a high performance transmitter/receiver optical communication chain and a broad variety of optoelectronic devices and measurement facilities.

The Ph.D. student will closely work with a postdoc, funded by the European program "MSCA Individual Fellowships". He will also benefit from an international collaboration with the research team of Prof. Octavia A. Dobre, from Memorial University, Canada, a research mobility being planned during the Ph.D. thesis.

References

[1] V. Niemelä, J. Haapola, M. Hämäläinen and J. Iinatti, *An Ultra Wideband Survey: Global Regulations and Impulse Radio Research Based on Standards*, in IEEE Communications Surveys & Tutorials, vol. 19, no. 2, pp. 874-890, 2017.

[2] M. Di Benedetto, T. Kaiser, A. Molisch, I. Oppermann, C. Politano, D. Porcino, *UWB Communication Systems: A Comprehensive Overview*, Hindawi Publishing Corporation, EURASIP Book Series on Signal Processing and Communications, Volume 5, 2006.

[3] M. Stanciu, *On the blind estimation of the signal parameters in the framework of an intelligent IR-UWB*, Université de Bretagne Occidentale, France, April 2011.

[4] R. Akbar, *Contribution to the design of an intelligent impulse radio ultra wideband system*, Ph.D. thesis, Université de Bretagne Occidentale, France, January 2013.

[5] H. Taki, *On Ultra-Wideband over Fiber Transmission Systems Employing Semiconductor Optical Amplifiers*, Ph.D. thesis, ENIB, France, September 2017.

[6] T. Yaacoub, *New approaches for UWB channel estimation relying on the compressed sampling of IR-UWB signals with finite rate of innovation*, Ph.D. thesis, Université de Bretagne Occidentale, France, October 2017.

[7] M. Stanciu, S. Azoub, E. Radoi, A. Serbanescu, *A Statistical Analysis of Multipath Interference for Impulse Radio UWB Systems*, Journal of the Franklin Institute 352 (2015), pp. 5952-5967, December 2015.

[8] H. Taki, S. Azou, A Hamie, A. Al Housseini, A. Alaeddine, A. Sharaiha, *Improving the power efficiency of SOA-based UWB over fiber systems via pulse shape randomization*, Optical Fiber Technology 31, 161-167, 2016.

[9] H. Taki, S. Azou, A. Hamie, A. Al Housseini, A. Alaeddine, A. Sharaiha, *Simple pre-distortion schemes for improving the power efficiency of SOA-based IR-UWB over fiber systems*, Optics communications 382, 225-231, 2017.

[10] H. Taki, S. Azou, A. Hamie, A. Al Housseini, A. Alaeddine, A. Sharaiha, *On phaser-based processing of impulse radio UWB over fiber systems employing SOA*, Optical Fiber Technology 36, 33-40 , 2017.

[11] D. Espes, A.M. Pistea, C. Canaff, I. Iordache, P. Le Parc, E. Radoi, *New Method for Localization and Human Being Detection using UWB Technology: Helpful Solution for Rescue Robots*, IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS2013), November 3-8, 2013, Tokyo, Japan.

[12] T. Yaacoub, A. M. Pistea, R. Youssef, E. Radoi, G. Burel, *Compressed sampling of bandpass signals with finite rate of innovation: application to UWB channel estimation and indoor accurate localization*, Signal Processing Journal, Vol. 33, No. 4, pp. 415 - 440, October-December 2016.

[13] R. Akbar, E. Radoi, S. Azou, M. Najam-ul-Islam, *Low-complexity synchronization algorithms for orthogonally modulated IR-UWB systems*, EURASIP Journal on Wireless Communications and Networking, 2013:199, July 2013.

[14] R. Akbar, E. Radoi, S. Azou, *A Non-Data-Aided Rapid Synchronization Method for UWB Impulse Radio*, IEEE Communications Letters, Vol. 16, No. 8, pp. 1308-1311, 2012.

[15] R. Akbar, E. Radoi, S. Azou, *Maximum Likelihood and Orthogonal Subspace based Approach for Improved IR-UWB Channel Estimation*, Proceedings of 18th European Signal Processing Conference (EUSIPCO 2010), Aalborg, Danemark, August 23-27, 2010, pp. 1145-1149, ISSN 2076-1465.

[16] T. Yaacoub, R. Youssef, E. Radoi, G. Burel, *Low Complexity FRI Based Sampling Scheme For UWB Channel Estimation*, EUSIPCO 2016, pp. 657-661, Budapest, Hungary, 29 August - 2 September 2016.

[17] T. Yaacoub, O. A. Dobre, R. Youssef, E. Radoi, *Optimal Selection of Fourier Coefficients for Compressed Sensing-Based UWB Channel Estimation*, IEEE Wireless Communications Letters, Volume 6, Issue 4, pp. 466 - 469, 2017.

[18] D. L. Donoho, *Compressed sensing*, IEEE Trans. Inf. Theory, vol. 52, no. 4, pp. 1289–1306, Apr. 2006.

[19] A. H. Muqaibel and M. T. Alkhodary, *Practical application of compressive sensing to ultra-wideband channels*, IET Commun., vol. 6, no. 16, pp. 2534–2542, Nov. 2012.

[20] H. Nan, Y. Gu and H. Zhang, *Optical Analog-to-Digital Conversion System Based on Compressive Sampling*, in IEEE Photonics Technology Letters, vol. 23, no. 2, pp. 67-69, Jan.15, 2011.

[21] T. P. McKenna, *Wideband Photonic Compressive Sampling System*, Journal of Lightwave Technology, vol. 34, No. 11, 2016.

[22] M. Shehata, H. Mostafa and Y. Ismail, *On the Theoretical Limits of the Power Efficiency of Photonically Generated IR-UWB Waveforms*, in Journal of Lightwave Technology, vol. 36, no. 10, pp. 2017-2023, May15, 15 2018.

[23] S. Sharma, et al., *A New Sparse Signal-Matched Measurement Matrix for Compressive Sensing in UWB Communication*, in IEEE Access, vol. 4, pp. 5327-5342, 2016.

[24] J. W. Choi, et al., *Multi-human detection algorithm based on an impulse radio ultra-wideband radar system*, IEEE Access 4 (2016): 10300-10309.

Required degree and skills:

- Master degree (or equivalent) in signal processing, telecommunications or electrical engineering.

- Solid background in signal processing, digital communications, telecommunications and/or optical communication.

- Good programming skills in general and knowledge of Matlab in particular are desired.

Application details and contact information:

The application should contain a CV, a cover letter, recent university records and reference letters.

Please note that as part of selection, short-listed candidates will be invited for interview shortly after the deadline.

Address all applications to:

Prof. Emanuel Radoi / Email: emanuel.radoi@univ-brest.fr / Tél.: +33.(0)2.98.01.83.35

Prof. Stéphane Azou / Email: azou@enib.fr / Tél.: (+33) 2.98.05.66.44

Apply before May 17th 2019