ДЕРЖАВНИЙ ВИЩИЙ НАВЧАЛЬНИЙ ЗАКЛАД
«УЖГОРОДСЬКИЙ НАЦІОНАЛЬНИЙ УНІВЕРСИТЕТ»
(м. УЖГОРОД, УКРАЇНА)
КОШИЦЬКИЙ ТЕХНІЧНИЙ УНІВЕРСИТЕТ
(м. КОШИЦЕ, СЛОВАЦЬКА РЕСПУБЛІКА)

ISSN 2218-5348

МІЖНАРОДНИЙ НАУКОВИЙ ВІСНИК

Випуск 1 (12)

Матеріали Міжнародної науково-практичної конференції
«Науковий парк як універсальна регіональна структура інноваційної діяльності»
(м.Ужгород, Україна – м.Кошице, Словацька Республіка, 3 березня 2016 р.)

Ужгород – Кошице
2016

УДК 001:378

Вісник містить наукові статті і тези доповідей, проголошених та обговорених на Міжнародній науково-практичній конференції «Науковий парк як універсальна регіональна структура інноваційної діяльності», проведеній Ужгородським національним університетом спільно з Кошицьким технічним університетом (Словацька Республіка) 3 березня 2016 року в рамках наукового проекту «Інноваційний університет – інструмент інтеграції в європейський освітній і науковий простір».

Видання здійснено за підтримки Міжнародного Вишеградського фонду.

STATE UNIVERSITY
«UZHHOROD NATIONAL UNIVERSITY»
(UZHHOROD, UKRAINE)
TECHNICAL UNIVERSITY OF KOŠICE
(KOŠICE, SLOVAK REPUBLIC)

ISSN 2218-5348

INTERNATIONAL SCIENTIFIC HERALD

Edition 1 (12)

Materials of International scientific and practical conference
"Science Park as universal regional structure of innovative activity"
(Uzhhorod, Ukraine – Košice, Slovak Republic, March 3, 2016)

Uzhhorod – Košice
2016

UDC 001:378

The Herald contains scientific papers and report theses, enunciated and discussed at the International scientific and practical conference "Science Park as universal regional structure of innovative activity", held on March 3, 2016, by Uzhhorod National University together with the Technical University of Košice (Slovak Republic) as part of implementation of the research project "Innovative university – tool of integration to European educational and research area".

The publication is issued with the financial support of the International Visegrad Fund.

EMBEDDED SENSOR NODE FOR UWB RADAR NETWORK BASED SHORT-RANGE TRACKING OF MOVING PERSONS

M. Drutarovsky, D. Kocur, O. Petura, J. Fortes, S. Slovak, M. Laban, P. Galajda, A. Pietrikova, P. Kazimir and M. Svecova
Technical University of Kosice, Kosice, Slovakia
fMilos.Drutarovsky, Dusan.Kocurg@tuke.sk

Ultra Wide Band (UWB) radar is a very perspective technology for short-range tracking of moving persons. UWB radar sensor network employing the centralized data fusion method can significantly improve tracking capabilities of more people in complex building environments. We present design prototype of sensor node based on M-sequence UWB radar front-end and embedded Linux based control unit as a basic building block of such sensor network. Embedded control unit provides processing power for preprocessing of received raw radar signals and compression of data sending to the data fusion center. Estimation of coordinates is performed by application of signal processing algorithms running locally in sensor node on high performance quad-core ARM CPU. Low-rate data stream of compressed target coordinates is send from the sensor node to the data fusion center by using narrow-band FSK modulation in free Short Range Devices (SRD) 868-870 MHz frequency band concurrently with operation of UWB radar front-end. Communication and synchronization of sensor node and data fusion center is controlled by ARM Cortex-M3 microcontroller that is also part of embedded control unit. The first experimental results obtained from our prototype show very good performance of developed UWB sensor node with significantly lower power consumption than previously used PC platform.

I. INTRODUCTION

The Ultra Wide Band (UWB) radar systems have a variety of potential applications including through wall and through fire detection and tracking of moving persons in surveillance systems and during security operations. UWB radars use for these scenarios relatively low frequency 100 MHz to 5 GHz signals with large fractional bandwidth. This allows create a UWB sensor with a suitable tracking resolution that also has an ability to penetrate many common materials such as wood, ground, snow, plastic, concrete, rock, light foliage, etc. Another potential advantage is providing only low-resolution images that do no not break human privacy in surveillance systems in contrary to e.g. camera based systems. Such sensors are able to detect moving person by measuring changes in the impulse response of the environments [1]. In the above outlined applications, a short-range UWB radar (range up to 20-25 m) is usually applied and we refer these scenarios as short-range tracking.

Pseudo-noise maximum length binary sequence (Msequence) UWB radar [2], [3] provides several inherent advantages for short-range tracking. It can emit continuous low power UWB signals in the range only a few mW even for through-wall monitoring applications. This is orders of magnitude lower power level than typical GSM mobile or even WiFi hotspots emit during transmission and M-sequence UWB radar can be safely used for tracking of people. Absence of short-time large power peaks in emitted M-sequence UWB radar signals allows use relatively simple electronic components in the radar front-end. In contrary to standard radar, M-sequence radar must perform additional deconvolution of received signals in order to provide Time of Arrival (ToA) required for further steps of applied tracking algorithms. This additional processing step must be performed by radar signal processing unit and can be regarded as disadvantage of Msequence radar in comparison with traditional radars using narrow-pulse UWB signals.

Fortunately, nowadays Central Processing Units (CPU) can perform this deconvolution only with a fraction of their processing power so this is not a problem in real people tracking applications. M-sequence UWB radars could even be used for detection of large static objects (e.g. large walls in buildings [4]) but such applications require more complex radar configurations, significantly more processing power and typically provide worst results in comparison with detection and tracking of moving persons.

The problem of short-range detection and tracking of moving persons have been studied e.g. in [5], [6], [7], [8], [9]. However, the problem of multiple human tracking in real complex environments has been less well addressed. Experiences received at several measurement campaigns with UWB radar systems for through wall tracking of moving persons have shown that a single handheld radar (with one transmitting and two receiving antennas) is able to detect very often a person moving closest to the radar antennas only, whereas it is not able to detect the remaining targets [10]. This phenomenon results from the fact that due to the frequency band employed by the UWB radar a person moving nearby the radar antennas reflects and absorbs the energy of electromagnetic waves emitted by the transmitting antenna but only a negligible part of electromagnetic wave energy is transmitted through the person body to a certain region located behind the person where the second target can be located. The similar effect can be identified, if the person moving nearby the radar antennas is located between the second target and receiving antenna what results in that this person absorbs the energy of the electromagnetic waves reflected by the second targetand hence, only a negligible part of energy of electromagnetic waves reflected by the second target can be received by the radar.

In order to solve this problem, a novel approach for shortrange tracking of moving persons was proposed in [11]. This approach uses application of a UWB sensor network employing proper data fusion methods. The UWB sensor network considered in [11] was represented by a set of sensors - UWB radars (each with one transmitting and two receiving antennas) connected by LAN communication network. The particular sensors have to be located in the monitored region in such a way as to cover the region of interest as best as possible. At the same time it is expected they are able to provide some diversity with regard to targets positioning. Each sensor is able to detect some persons from the total number of targets and at the same time it is able to estimate their coordinates. The target coordinates provided by all sensors are transmitted to the data fusion center and subsequently they are processed by data fusion methods.

In this paper we present new prototype of sensor node based on M-sequence UWB radar front-end and embedded Linux based control unit as a basic building block for the sensor network employing proposed data fusion method. Estimation of coordinates is performed by application of signal processing algorithms running locally in the sensor node CPU and lowrate data stream of compressed target coordinates is send wirelessly from the sensor node to the data fusion center by using narrow-band FSK modulation in free Short Range Devices (SRD) frequency band.

II. TOPOLOGY AND PERFORMANCE OF UWB SENSOR NETWORK WITH DATA FUSION CENTER

Supported UWB sensor network uses star topology with one master and several slave UWB sensor nodes. Sensor nodes are represented by M-sequence radars and data fusion center is implemented in a standard Personal Computer (PC). Data fusion for considered UWB sensor network has centralized architecture shown in Fig. 1 [11]. The radar signals acquired by each sensor are independently processed by the procedure for through wall tracking of multiple moving targets proposed in [12]. It consists of several phases, namely background subtraction, weak signal enhancement, detection, ToA estimation, wall effect compensation [13] and target localization. Then, the target coordinates are processed by the fusion center. Here, we assume that the data provided to the fusion center are time-synchronized and transformed into the common coordinate systems. The sets of such data from each sensor node represents the input data for MTT system.

The performance of the proposed approach for short-range tracking of moving persons was demonstrated by processing of real signals acquired by the UWB sensor network consisting of two M-sequence UWB channel sounders and two M-sequence UWB radars in [11]. The measurement scenario is given in the Fig. 2(a) representing a school corridor of approximate size 7 m   15 m. Sensor nodes were placed in the opposite room corners and labelled as sensor S1, S2, S3 and S4 (Fig. 2(a)).

Each UWB sensor node was equipped with one transmitting (Tx) and two receiving double-ridged horn antennas (Rx1, Rx2). The raw radar signals have been independently processed by methods of background subtraction (exponential averaging), detection (CFAR detector), ToA estimation (so called

ToA association responsible also for deghosting task solution [14]) and localization (direct calculation). The estimated target coordinates after time-synchronization and transformation into the common coordinate system are depicted particularly for each sensor in Fig. 2(b)-2(e). As we can see from these figures, all sensors have captured the biggest amount of target reflections in their vicinity whereby sensors S1 and S2 have covered approximately 1=4 of the monitored area but sensors S3 and S4 only around 1=8 of it. The low performance of the sensor S3 in comparison to the sensor S1 was due to the application of an older type of antennas for the sensor S3. The decreased coverage of the monitored region by the sensor S4 results from its short-range capability.

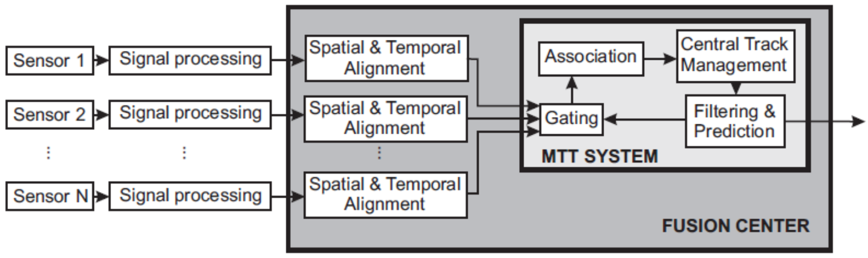

Fig. 1. Centralized data fusion architecture including MTT system. Sensor and Signal processing block are included in each sensor node, Fusion Center is implemented in a PC.

These results clearly demonstrate significantly improved tracking precision of proposed UWB sensor network approach. Further details about used algorithms can be found in [11]. Note that described experimental results were acquired by UWB sensor network with wired communication channels from sensors to the data fusion center. Sensor nodes were represented by large experimental M-sequence UWB radar and channel sounder systems. Next sections describe new compact hardware UWB sensor node prototype developed within TECHNICOM project in cooperation with TU Ilmenau Service GmbH (ILMSENS) [15], our German cooperating partner in the TECHNICOM project. Our new UWB sensor node contains powerful embedded CPU and wireless communication channel that can be used for communication with data fusion center concurrently with UWB radar front-end operation.

III. PROPOSED UWB SENSOR NODE ARCHITECTURE

We build-up UWB sensor around the control unit based on 11 cm 8:5 cm embedded UDOO minicomputer equipped with Freescale i.MX 6 ARM Cortex-A9 quad-core 1 GHz CPU and Atmel SAM3X8E ARM Cortex-M3 microcontroller (MCU) [16]. UDOO is an open hardware, low-cost computer platform for which complete schematic is publicly available. Relatively unusual combination of high-performance CPU with embedded MCU on one board allows to separate signal processing and communication algorithms by running communication and synchronization functions on the MCU. On board CPU and MCU are fully user programmable and this feature provides high flexibility during firmware development. Moreover we can extend functionality of CPU and MCU by using available interfaces and General Purpose Input Output (GPIO) that are well documented for all UDOO hardware components. Main features of developed UWB sensor node are summarized in the following subsections.

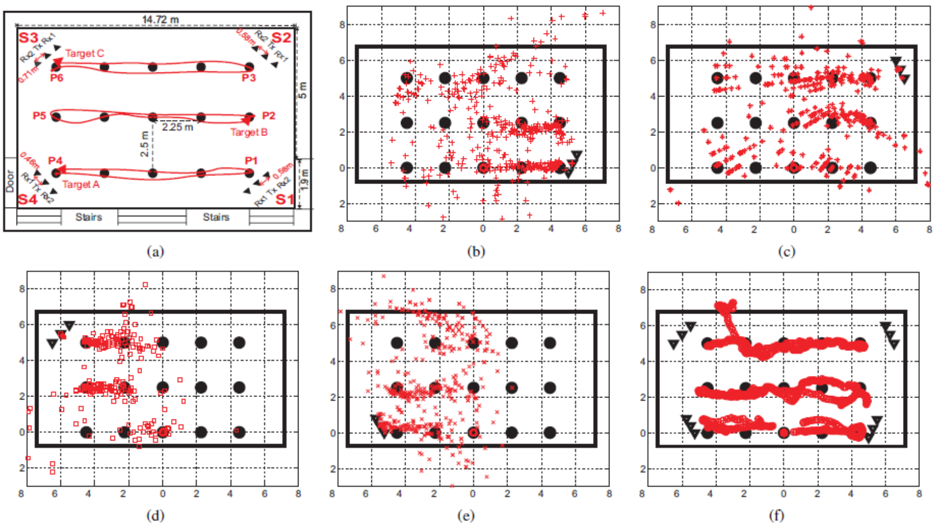

Fig. 2. Experimental confirmation of target tracking coordinates estimation improvement by using MTT based signal processing in data fusion center [11]: (a) measurement scenario - corridor scheme with the antennas layout for whole UWB sensor network, (b) local estimation by sensor S1, (c) local estimation by sensor S2, (d) local estimation by sensor S3, (e) local estimation by sensor S4, (f) final estimation by data fusion from sensors S1&S2&S3&S4.

A. UWB Radar Front-End

Our UWB sensor node uses M-sequence UWB radar frontend with 12th order M-sequence developed by ILMSES. The front-end has 1 Tx and 2 Rx connectors and contains integrated custom high frequency Linear Feedback Shift Register (LFSR) pseudo-noise generator, 12.8 GHz clock generator, high-performance wide-band amplifiers, two AD converters working in sub-sampling mode and FPGA interface board. The UWB font-end is connected to our control unit by using standard USB interface. FPGA configuration bitstream is downloaded to the front-end FPGA by our control unit during sensor node start-up phase. The front-end provides pair (for each of 2 RX channels) Impulse Responses (IR) and each response has 212 □ 1 = 4095 elements. Number of IR per second (IR/s) are configurable by selection of number of averaging performed in the front-end FPGA hardware. For detection and tracking of moving people we typically use UWB radar front-end with 10-20 IR/s.

B. Data Processing

Data processing algorithms are performed by quad-core CPU, the most powerful component of the control unit. We implemented all processing blocks shown in Fig. 3 as portable ANSI-C functions to provide high flexibility for the final sensor node firmware development and future extensions. Measured impulse responses are obtained from Correlation block that performs deconvolution of received UWB radar signals by using highly optimized Hadamard transform and signal components permutations. The Background subtraction blocks extract week dynamic signals representing moving persons from static reflections. This operation significantly improves input signal to noise ratio that is required for proper operation of the following signal processing algorithms. Detection, Localization and Tracking blocks execute series of operations with the goal to estimate locally coordinates of moving people in the analyzed area. All computations are performed in 32-bit floating-point arithmetic by using quadcore CPU. Source codes and compiler settings are optimized for exploitation of SIMD based NEON extension available in ARM Cortex-A9 CPU. Thanks to multi-core architecture and 1 GHz clock frequency of CPU there is no problem with realtime data processing capabilities of used hardware and there is even reserve for more complex algorithms to be implemented in future.

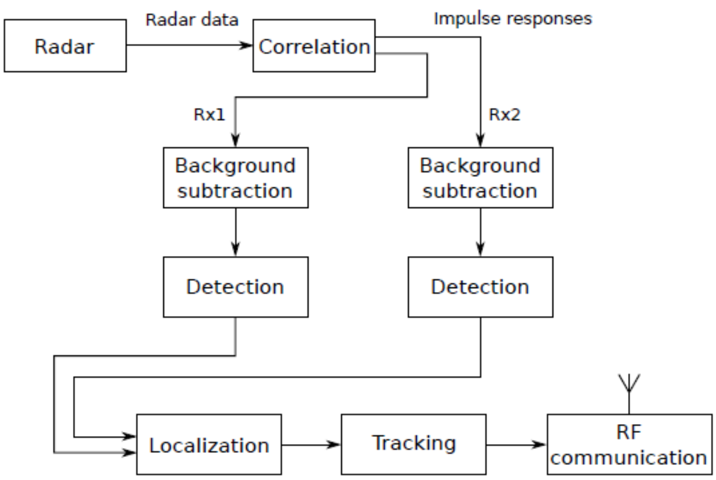

Fig. 3. Main components and signal processing blocks of UWB sensor node.

C. Support by Operating System

Control unit has to communicate with the radar front-end by using high high-level USB interface. In order to simplifysensor node firmware development and ensure simple portability to alternative hardware platforms in future we decided to use Operating System (OS). UDOO minicomputer can run Linux or

Android OS [16]. The Android is user oriented OS that is hard to customize. So we chose Linux to power our sensor node. There are several choices of Linux distributions for UDOO such as Ubuntu, Arch Linux ARM or Yocto Linux. We chose Yocto Linux because it is the minimalistic Linux distribution with very small footprint size and it is built for the target platform rather than distributed as a pre-compiled image. We used minimal Yocto image with just a USB storage driver installed. We also developed custom USB driver for UWB radar front-end which was available only for PC Windows OS. Yocto Linux, data processing and complete sensor node custom functions have 165 MB and are stored on the SD card. They are downloaded to the control unit DRAM memory during sensor node start-up booting phase.

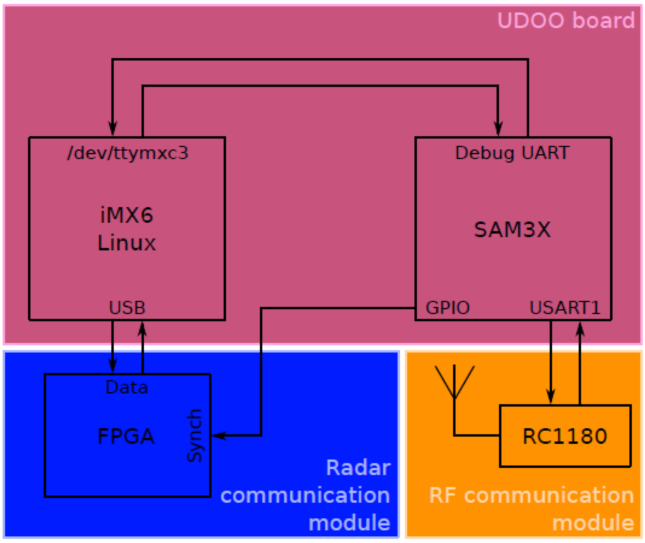

Fig. 4. Block diagram of complete UWB sensor node including interfaces and communication channels. GPIO pin of MCU synchronizes operation of UWB radar-front end with sub-millisecond precision.

D. Wireless Communication and Synchronization

In proposed sensor network we transmit data from the sensor node to the data fusion center for further processing. We are using the RF network working in license-free narrow-band SRD 868-870 MHz. As RF transceivers we use Radiocrafts RC1180 radio modules with narrow-band FSK modulation [17]. Locally estimated target coordinates that are computed by quad-core ARM CPU are sent to the SAM3X MCU via debug UART shared by ARM CPU and SAM3X MCU. The RF communication of the sensor node is controlled via USART1 interface by the Atmel SAM3X MCU on the UDOO board. Block diagram of complete UWB sensor node is shown in Fig. 4. The MCU performs also wireless synchronization of sensor node by using pilot signals (special synchronization packets) transmitted by data fusion center RF interface. Separation of data processing CPU and communication/synchronization MCU significantly simplified firmware development and allows real-time synchronization of sensor nodes with precision better than 1 ms that is much better than required for proper detection and tracking of moving people. MCU firmware is developed as bare-metal application by using GNU development tools for ARM MCUs.

E. Power Consumption

We selected UDOO based control unit not only due to it's compactness and high-performance of quad-core ARM CPU, but high priority in selection process was a possibility to operate it without active cooling. UDOO board can be operated from a 6-15 V DC switching power supply and total power consumption is 3.12 W @ 9961 MHz clock frequency. The power consumption can be slightly decreased to 2.90 W @ 792 MHz and 2.58 W @ 396 MHz, respectively. Complete standalone control unit including MCU and RF transceiver can be operating with only passive cooling thanks to the large metallic cooler attached directly to the quad-core ARM CPU.

IV. EXPERIMENTAL UWB SENSOR PROTOTYPE

Main components of developed UWB sensor node prototype are shown in Fig. 5. Complete embedded UWB sensor node prototype including also UWB radar front-end is placed in the aluminium box shown in Fig. 6. The basic functionality of prototype was confirmed by comparison of computed targets coordinates with reference Matlab computations. The prototype will be used for development and optimalization of CPU and MCU firmware as well as for final OS configuration. The prototype has no ventilation holes in order to allow testing thermal behavior of all sensor node components. It is expected that final design will require additional thermal optimalization as UWB radar front-end is additional significant source of heat.

Fig. 5. Building blocks of developed UWB sensor node prototype: UDOO based control board with RF communication module (left), UWB radar frontend developed by ILMSENS (middle), back panel (right).

V. CONCLUSIONS

We described new UWB sensor node prototype developed with the TECHNICOM project in cooperation with ILMSENS company. Our UWB sensor node is optimized for star topology of wireless sensor network with centralized data fusion center. It uses M-sequence UWB radar frontend with 12th order pseudo-random sequence developed by partner ILMSENS company. We build up complete UWB sensor around the control unit based on embedded UDOO minicomputer running Yocto Linux distribution optimized for embedded applications. Radar signals preprocessing and locally executed signal processing algorithms are performed by quad-core ARM Cortex-A9 CPU @ 1 GHz available on UDOO minicomputer. Compressed estimations of target coordinates are transferred to the data fusion center by using narrow-band FSK modulation in free SRD 868-870 MHz frequency band concurrently with operation of UWB radar front-end. We control communication between sensor node and data fusion center as well as network synchronization by using ARM Cortex-M3 microcontroller that is also part of UDOO minicomputer and is running in parallel with main quad-core ARM CPU. Our developed firmware for both ARM processors was tested and results were compared with Matlab reference implementation of signal processing algorithms. First experimental results confirmed correctness of implemented algorithms and also correct operation of UWB sensor node initialization, control, communication and synchronization functions. Power consumption of our control unit is only 3 W. Developed hardware has modular architecture that we can easily extend from hardware as well software point of view. We will use these features in future development steps when UWB radars acquired within TECHNICOM project will be available and used in the complete UWB sensor network performance testing.

Fig. 6. Complete UWB senzor node with all components placed in aluminium box. Back panel contains SMA connector for RF antenna in SRD frequency band, power switch, diagnostic LEDs, configuration switches, USB and UART interfaces to be used for further firmware development.

ACKNOWLEDGMENT

This work is the result of the Project implementation: University Science Park TECHNICOM for Innovation Applications Supported by Knowledge Technology, ITMS: 26220220182, supported by the Research & Development Operational Programme funded by the ERDF.

REFERENCES

[1] P. Withington, H. Fluhler, and S. Nag, "Enhancing homeland security with advanced UWB sensors," Microwave Magazine, IEEE, vol. 4, no. 3, pp. 51–58, Sept. 2003.

[2] D. Daniels, Ground Penetrating Radar, 2nd ed. London, U.K.: The Institution of Electrical Engineers, July 2004, ch. M-sequence radar.

[3] J. Sachs, M. Aftanas, S. Crabbe, M. Drutarovsky, R. Klukas, D. Kocur, T. Nguyen, P. Peyerl, J. Rovnakova, and E. Zaikov, "Detection and Tracking of Moving or Trapped People Hidden by Obstacles using Ultra-Wideband Pseudo-Noise Radar," in 5th European Radar Conference (EuRAD 2008), Amsterdam, The Netherlands, Oct. 2008, pp. 408–411.

[4] M. Aftanas and M. Drutarovsky, "Imaging of the Building Contours with Through the Wall UWB Radar System," Radioengineering, vol. 18, no. 3, pp. 258–264, September 2009.

[5] S. H. Chang et al., "People Tracking with UWB Radar Using a Multiple-Hypothesis Tracking of Clusters (MHTC) Method," in Int J Soc Robot (2010) 2. Springer, Jan. 2010, p. 3 18.

[6] S. Z. Gurbuz, W. L. Melvin, and D. B. Williams, "Comparison of radarbased human detection techniques," in Proc. 41st Asilomar Conf. On Signals, Systems and Computers, 2007, pp. 2199–2203.

[7] S. S. Gauthier and W. Chamma, "Surveillance through concrete walls," in Proc. of SPIE -C3I Technologies for Homeland Security and Homeland Defense III, Sept. 2004, pp. 597–608.

[8] S. Nag et al., "Ultrawideband through-wall radar for detecting the motion of people in real time," Proc. SPIE-Radar Sensor Technology and Data Visualization, vol. 4744, pp. 48–57, July 2002.

[9] S. S. Ram and H. Ling, "Through-Wall Tracking of Human Movers Using Joint Doppler and Array Processing," IEEE Geoscience and Remote Sensing Letters, vol. 5, no. 3, pp. 537–541, July 2008.

[10] J. Rovˇnakov´a, Complete signal processing for through wall tracking of moving targets. Germany: LAP LAMBERT Academic Publishing, Sept. 2010.

[11] J. Rovˇnakov´a and D. Kocur, "Short Range Tracking of Moving Persons by UWB Sensor Network." Manchester, Great Britain: EuRAD, Oct. 2011, pp. 321–324.

[12] ——, “UWB Radar Signal Processing for Through Wall Tracking of Multiple Moving Targets.” Paris, France: EuRAD, Oct. 2010, pp. 372–375.

[13] M. Aftanas, J. Sachs, M. Drutarovsky, and D. Kocur, “Efficient and Fast Method of Wall Parameter Estimation by Using UWB Radar System,” Frequenz, vol. 63, no. 11-12, pp. 231–235, Nov. 2009.

[14] J. Rovˇnakov´a and D. Kocur, “TOA Estimation and Data Association for Through Wall Tracking of Moving Targets,” EURASIP Journal on Wireless Comm. and Networking, The special issue: Radar and Sonar Sensor Networks, vol. 2010, Sept. 2010.

[15] ILMSENS. [Online]. Available: http://www.ilmsens.com/

[16] UDOO dual & quad mini PC for Androind and Linux. [Online]. Available: http://www.udoo.org/udoo-dual-and-quad/

[17] RC11xx-RC232 Low Cost Multi-Channel RF Transceiver Module. [Online]. Available: http://www.radiocrafts.com/uploads/rc11xxrc232 data sheet 1 46.pdf

ЗМІСТ

Наукове видання

МІЖНАРОДНИЙ НАУКОВИЙ ВІСНИК
INTERNATIONAL SCIENTIFIC HERALD

Випуск 1 (12)

Свідоцтво про державну реєстрацію друкованого засобу масової інформації КВ №20546-10346Пр, видане Міністерством юстиції України 15.01.2014 р.

Відповідальний за випуск І.В. Артьомов
Упорядник А.І. Гусь
Коректура: Т.М. Алексєєва, Л.І. Середа
Технічне редагування: М.І. Іванова, О.І. Гурчумелія
Комп'ютерна верстка та дизайн обкладинки А.І. Бродич

Підписано до друку 30.03.2016 р.
Ум.друк.арк. 29,2
Гарнітура Times New Roman
Формат 60х84/8 Зам.№28
Тираж 300 прим.

Оригінал-макет виготовлено
в редакційно-видавничому відділі ДВНЗ «УжНУ»
88015, м. Ужгород, вул. Заньковецької, 89,
E-mail: dep-editors@uzhnu.edu.ua

Віддруковано ПП А.А. «Демидов»
88000 м. Ужгород, вул. Митрака, 25

М-72

Міжнародний науковий вісник: збірник наукових статей за матеріалами Міжнародної науково-практичної конференції «Науковий парк як універсальна регіональна структура інноваційної діяльності», Ужгород-Кошице, 3 березня 2016 року /ред. кол. В.І.Смоланка (голова), І.В.Артьомов та ін. – Ужгород: ДВНЗ «УжНУ», 2016. – Вип. 1(12). – 254 с.

ISSN 2218-5348

УДК 001:378

International Scientific Herald: collection of scientific papers on materials of International scientific and practical conference "Science Park as universal regional structure of innovative activity", Uzhhorod-Kosice, March 3, 2016 / ed. count. V. Smolanka (Chairman), I. Artjomov and others. – Uzhhorod: SU "UzhNU", 2016 – Ed. 1 (12). – 254 p.