IMPACT OF INDUSTRY 4.0 TECHNOLOGIES ON THE EMPLOYMENT OF THE PEOPLE WITH EYE PROBLEMS: A CASE STUDY ON THE SPATIAL COGNITION WITHIN INDUSTRIAL FACILITIES

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Abstract: *Nowadays, Industry 4.0 technologies simplify the blind and visually impaired (B&VI) employment and make the work conditions B&VI friendly. The interviewing of B&VI and the analysis of literature and Internet resources show that two features must be implemented at least – detection of unexpected obstacles in front of the B&VI on the distances of up to 1 m and the B&VI remote localization. The developed soft-/hardware complex uses wearable Raspberry Pi 3 B microcomputer with an ultrasonic range sensor HC-SR04 to solve the first problem and the Bytereal iBeacon fingerprinting to work out the second one. The presented approach was successfully tested at the three-workroom industrial facilities – the B&VI detected obstacles and the blind companion remotely localized the B&VI via the iBeacon fingerprinting, HTML dynamic website, and MQTT protocol. This satisfies the requirements to the accessibility, safety, and problem solving; the ability to apply other assistive technologies meets the flexibility feature of the four-hospitality criterion.*

Key words: *Industry 4.0, smart city, employment, blind and visually impaired, spatial cognition, wearable assistive device*

JEL Classification: *O35, J21, J81, I15*

1. INTRODUCTION

Nowadays, Industry 4.0 and smart sustainable development and inclusive growth are commonly called as the trends and fourth industrial revolution [1-3]. Cyber-physical systems, Internet of Things (IoT), cloud and cognitive computing are the main constituents of this concept [2, 4]. These technologies have a huge impact on almost every aspect of the smart enterprise including the employment of people with disabilities and eye problems (blind and visually impaired, B&VI) in particular [5-7]. The competitive strength of smart cities is based on five driving forces [8] related to the smart enterprises: productive business environment; profitable regional economy; high employment level and qualified human resources; smart infrastructure; accessible natural and environmental resources; efficient banking and financial institutions. The B&VI employment rate is about 30 % worldwide nowadays [7]. The solution of this problem brings many benefits to both sides – enterprises have qualified employees and show social responsibility, B&VI have money, companionship, and a positive and valued self-identity [7]. The B&VI employees design mental maps of the premises based on the infrastructure elements such as tables and walls. This activity takes a few hours or days – the duration depends on the dimensions and B&VI experience. The main difficulties of B&VI are about detection of unexpected obstacles such as trolleys and boxes. The main drawbacks of blind companions are about remote localization of the B&VI. In this work, a case study on the B&VI spatial cognition within three-workroom industrial facilities is discussed using the assistive device with the following features:

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- detection of unexpected obstacles in front of the B&VI on the distances of up to 1 m with ultrasonic range sensor HC-SR04 [9] installed on the Raspberry Pi 3 B board [10];

- Raspberry Pi 3 B based indoor localization [11] of the B&VI using the received signal strength indicator (RSSI) from the Bytereal iBeacon Bluetooth low energy (BLE) 4.0 near field orientation modules with a cover range of 50 m [10-14], MQTT IoT protocol [15], and HTML dynamic website.

Then, this information is said to the B&VI and / or transmitted to the blind companion. This specific configuration satisfies the basic requirements to the assistive devices for the B&VI spatial cognition at the industrial facilities. This functionality was designed via the interviewing of B&VI at the Instituto para Ciegos y Débiles Visuales "Ezequiel Hernández Romo" (San Luis Potosi, Mexico) and the analysis of literature (e.g. [11, 16-20]) and Internet (e.g. [21-23]) resources.

The goal of this paper is to show how Industry 4.0 technologies simplify the B&VI employment and make their work conditions more B&VI friendly. Even a small improvement of the B&VI assistive devices implies a large social benefit.

This paper is organized as follows: In Section 2, the related work is presented. In Section 3, the experimental testbed and iBeacon fingerprinting are discussed, and then a rule for the B&VI localization is proposed. In Section 4, the B&VI spatial cognition is presented using the assistive device with Raspberry Pi 3 B and ultrasonic range sensor HC-SR04 for the detection of obstacles on the distances of up to 1 m; the blind companion finds the B&VI location via iBeacon RSSIs and HTML dynamic website; different equipment communicate with each other based on the MQTT IoT protocol. Conclusions are summarized in Section 5.

2. RELATED WORK

In the last decade, technologies of smart factories / cities drastically improved the quality of life and work conditions, and hence the regional economies got new impulse for the growing. In particular, people with disabilities received new opportunities for employment and self-realization. Analysis of the successful projects shows three important development stages:

- formation of the smart governance;

- training of the end-users;

- development of the smart assistive infrastructure such as the yellow tactile pavings, wheelchair ramps, virtual or real blind companions, etc.

The smart city four-hospitality criterion [8] is applicable to the smart enterprises as well, i.e. industrial facilities must be accessible, safe, flexible, and able to solve the problems of B&VI.

Most of the literature deals with IT-based technologies for the B&VI spatial cognition within smart factories. The results were mainly published in the journals and conference proceedings related to the IoT and assistive devices for B&VI since these technologies are based on the intelligent algorithms and IoT soft-/hardware.

Nowadays, location systems use two principal techniques for positioning – radio frequency (RF) / acoustic / optical triangulation / trilateration [24, 25] and fingerprinting [26, 27]. Triangulation [25] and trilateration [24] determine absolute or relative locations by the measurement of distances using the geometry of triangles and circles / spheres, respectively. The ranges are identified via RF (WiFi, Bluetooth, RFID [10]) technologies, acoustic (e.g. HC-SR04) and / or optical (e.g. GP2Y0A21) sensors. Fingerprinting uses machine learning to match the B&VI location based on a predefined set of characteristics of sensor signals at each of the locations.

In [11], different indoor localization techniques (Angle of Arrival (AoA), Time of Flight (ToF), Return Time of Flight (RTOF), RSSI, Channel State Information (CSI), etc.) and technologies (WiFi, Ultra Wideband (UWB), Visible Light, etc.) are described in detail. Three approaches of the object localization are presented: the user device utilizes the reference or anchor nodes to obtain its relative location; a set of the reference or anchor nodes passively obtains the position of the user connected to the reference node; proximity detection of the distance between a user and a point of interest. Existing localization systems are evaluated from the perspective of energy efficiency, availability, cost, reception range, latency, scalability, and tracking accuracy. It is pointed out that the final solution depends on the various factors such as smart factory infrastructure, existing soft-/hardware, localization technique.

In [16], the behavior of B&VI is discussed when they explore unknown places. It helps to build a more appropriate interface and dialogue system. A study on how the B&VI verbalize a route with a set of elements and rules is presented. A concept of the blind companion is shown but the soft- and hardware are not discussed.

In [17], an ambient intelligence system RUDO for B&VI is presented. It consists of several modules: recognition of approaching people, alerting to other household members' movement in the apartment, work on a computer including writing in Braille on a regular keyboard, supervision of sighted children, cooperation of a sighted and B&VI, control of heating and zonal regulation by the B&VI. Here, the home solution is discussed only.

In [18], the information and assisted navigation system for the B&VI performs voice-controlled navigation inside the building. The location system was developed based on Bluetooth technology. The system locates the user and sends the instructions to reach the desired destination after the environment is equipped with sufficient sensors. Here, the obstacle detection relies on the user abilities only.

In [13], a measurement study of the Estimote, GELO, and Wizturn Pebble iBeacons and iOS / Android mobile device platforms shows that iBeacon RSSI values vary significantly across iBeacon vendors, mobile device platforms, deployment height of the device, indoor / outdoor environmental factors, and obstacles. In addition, it was pointed out that iBeacons can be used indoor and outdoor both, but GPS is unusable inside buildings. Hence, the design of the location estimation model is a complicated problem.

In [19] and [20], QR code based indoor navigation systems are presented. This approach is feasible if the QR code is in front of the camera. In [28], a camera reads AprilTags and then calculates the location and orientation of the device. However, it is a common situation when QR codes and AprilTags cannot be captured by the camera, and hence the B&VI location is unidentifiable.

In [26] and [27], a promising approach of the location fingerprinting with iBeacons is presented. In [26], the training data is collected from a Bluetooth-enabled iOS client device, and then is pushed to and stored in the computational cloud for future retrieval and use. In [27], a detailed study of the user fingerprinting localization with 19 BLE beacons distributed around 600 m^2 testbed is presented. The results show advantages of BLE beacons for positioning compared with WiFi fingerprinting. Machine learning algorithms are not applied in [26] and [27].

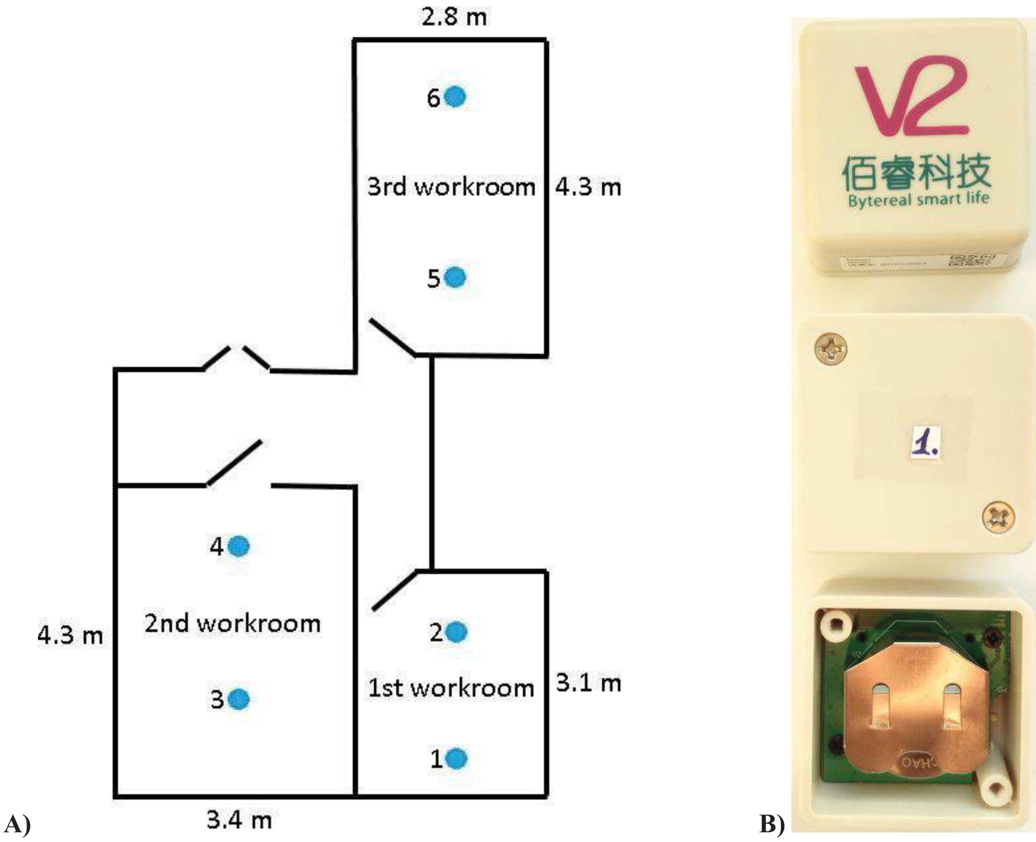
Nowadays, Industry 4.0 applies several IoT protocols such as MQTT, CoAP, XMPP, DDS, and AMQP [29, 30]. MQTT IoT software can be executed on thin clients like Arduino Uno since it takes approximately 10 KB of random access memory. It was shown that MQTT brokers work reliably with 100,000 publishers and 100 subscribers [29] that satisfies the requirements to the smart enterprise networks.

Analysis of the above-stated work shows that Industry 4.0 and smart city technologies simplify the B&VI employment and make their work conditions more B&VI friendly via IoT. For the time being, there is no universal soft-/hardware solution for smart factories. Hence, the development of case-oriented projects with four-hospitality criterion is the most effective approach to support the B&VI working activities.

3. EXPERIMENTAL TESTBED AND iBEACON FINGERPRINTING

The testbed is a small industrial facility of approximately 40 m^2 (see Figure 1, A; six blue dots represent the iBeacon fingerprinting points) in Vinnitsa city that is common to Ukraine. The area has an existing WiFi network with one access point within the testbed. Three Bytereal iBeacons (see Figure 1, B) were horizontally installed on the ceilings, workroom center adjusted. The distance between the floor and ceiling is 2.5 m.

Figure 1: A) Map of the experimental testbed; B) Three Bytereal iBeacons



Source: the map was designed and the photo was taken by authors (2018)

The Raspberry Pi 3 B board measures the RSSIs of Bytereal iBeacons at six points (blue dots in Figure 1, A) using the Python library Bluepy [12]. The 1st workroom iBeacon has a name BR522827 and Bluetooth address 20:18:ff:00:33:5d, 2nd – BR523803 and 20:18:ff:00:33:16, 3rd – BR523809 and 20:18:ff:00:33:19. The results are presented in Table 1. Sometimes, iBeacons are not detected – RSSI equals -120dBm in this case.

Table 1: RSSIs of Bytereal iBeacons

No. of the point	1st workroom iBeacon RSSI, dBm			2nd workroom iBeacon RSSI, dBm			3rd workroom iBeacon RSSI, dBm		
1	-66	-63	-64	-72	-75	-78	-81	-85	-85
	-61	-62	-69	-74	-75	-77	-91	-84	-87
	-61	-62	-75	-75	-76	-73	-84	-83	-85
	-72	-63	-75	-76	-74	-74	-87	-93	-84
	-67	-77	-62	-75	-75	-74	-86	-84	-86
2	-57	-64	-64	-65	-71	-67	-97	-88	-93
	-63	-58	-65	-67	-68	-72	-103	-92	-93
	-57	-57	-57	-67	-70	-71	-103	-93	-94
	-58	-57	-57	-72	-72	-71	-81	-92	-94
	-58	-57	-58	-68	-70	-71	-90	-92	-93
3	-89	-87	-89	-69	-76	-72	-97	-93	-92
	-89	-84	-77	-76	-80	-71	-89	-89	-91
	-79	-85	-89	-75	-85	-81	-88	-89	-81
	-95	-91	-89	-67	-70	-79	-95	-87	-92
	-92	-90	-84	-78	-71	-67	-96	-89	-92
4	-71	-71	-75	-69	-61	-58	-85	-84	-80
	-71	-71	-74	-67	-62	-58	-85	-83	-82
	-81	-85	-88	-69	-60	-57	-87	-82	-82
	-77	-89	-79	-65	-60	-60	-82	-82	-92
	-75	-74	-82	-56	-59	-60	-81	-82	-92
5	-98	-99	-95	-86	-96	-84	-66	-70	-66
	-95	-97	-97	-85	-89	-95	-70	-70	-66
	-96	-96	-100	-82	-90	-97	-68	-70	-71
	-97	-93	-93	-91	-96	-85	-71	-71	-68
	-95	-94	-98	-84	-96	-83	-71	-70	-75
6	-90	-96	-89	-93	-86	-87	-68	-72	-68
	-97	-88	-93	-93	-87	-86	-71	-69	-68
	-85	-84	-93	-90	-93	-85	-69	-72	-65
	-96	-93	-89	-88	-88	-99	-69	-70	-64
	-84	-87	-87	-91	-86	-85	-72	-70	-73

Source: the RSSIs were measured by authors (2018)

Analysis of the presented in Table 1 iBeacon fingerprinting RSSIs shows that the B&VI location can be uniquely identified with the following rule: if RSSI of some iBeacon is greater than -65 dBm or greater than any other RSSI more than 11 dBm then the B&VI is in the workroom where this iBeacon is installed.

4. THE B&VI SPATIAL COGNITION WITHIN INDUSTRIAL FACILITIES: AN ASSISTIVE DEVICE SOFT-/HARDWARE IMPLEMENTATION

The Raspberry Pi 3 B microcomputer and ultrasonic range sensor HC-SR04 are the main hardware components (see Figure 2). In addition, a small 5 MP Raspberry Pi camera was installed in the enclosure for the future image processing projects. The Arduino Mega board with Ethernet shield (see Figure 3) implement the simple web-server to start a location HTML dynamic website (see Figure 4) based on the data acquired from the MQTT broker. The interaction between MQTT clients and broker is shown in Figure 3: the B&VI with Raspberry Pi microcomputers are the MQTT publishers (Python library paho-mqtt [15] is applied), Arduino Mega board with Ethernet shield (Arduino library PubSubClient [31] is included) is the MQTT subscriber, the blind companion computer (Mosquitto software [31] is installed) with Windows 10 operating system is the MQTT broker. In this project, the Arduino hardware is used since additional sensors can be utilized additionally. This possibility is crucial for the future scaling of the system. For the time being, the price of one kit for ten B&VI is about USD 700.

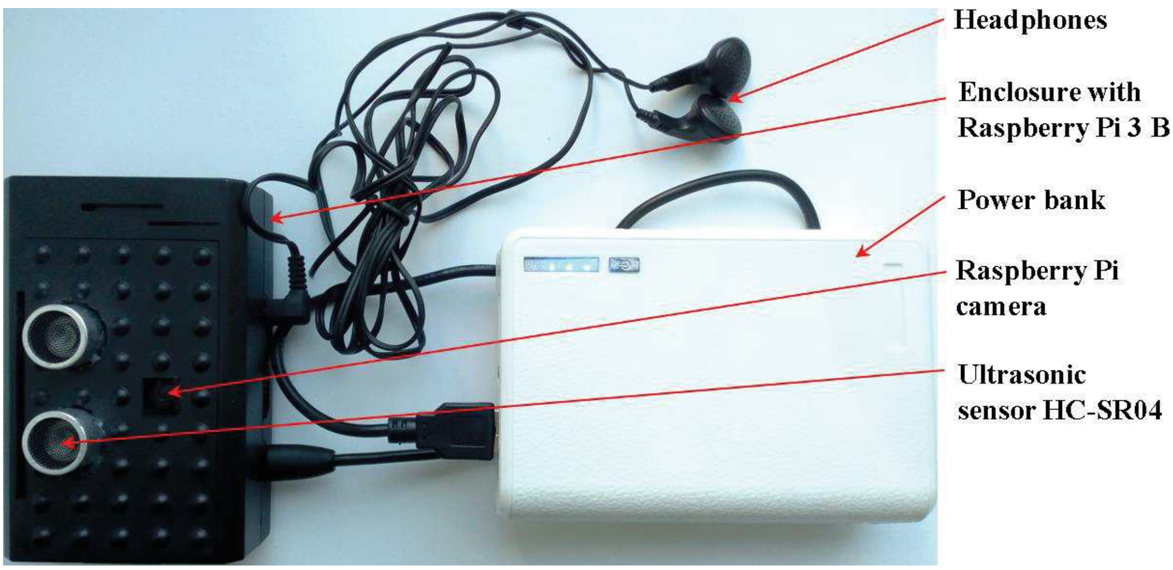
Detection of unexpected obstacles in front of the B&VI on the distances of up to 1 m is based on the ultrasonic detector HC-SR04, which works well on the range of up to 5 m [9]. The Raspberry Pi 3 B general purpose input / output pins are of maximum voltage 3.3 V and a power supply is 5 V. Hence, the voltage divider with resistors 1 kOhm and 2 kOhm is applied to the HC-SR04 Echo output. The Python code for acquiring the information from the HC-SR04 is similar to the program presented in [9]. Since HC-SR04 is not 100 % precise, the following rule is applied to avoid the mistakes: if three last values from the HC-SR04 sensor show that the distance to the obstacle is less than 1 m, it is considered that unexpected obstacle is in front of the B&VI. Since one program loop takes approximately 0.01 sec, detection of the obstacle in front of the B&V is about 0.1 sec, which is quite acceptable for the slowly walking B&VI. The information is pronounced in English to the B&VI via headphone(s) and the text-to-speech engine flite [32].

To acquire the iBeacon RSSIs and calculate the location, the Python code was developed similar to the program presented in [12]. For this purpose, the Bluepy library was installed. The B&VI location is encoded by six-digit number, where the first three digits is the person index number and the last three digits is the workroom code. For instance, "002003" means that a second person is in the third workroom. Then, this information is transmitted to the MQTT broker under the topic "/location/people".

The Python programs are downloaded from the Internet file server when the Raspbian is started, and hence it is possible to update the software remotely. If the Internet is not connected, previously downloaded files are loaded from the SD card.

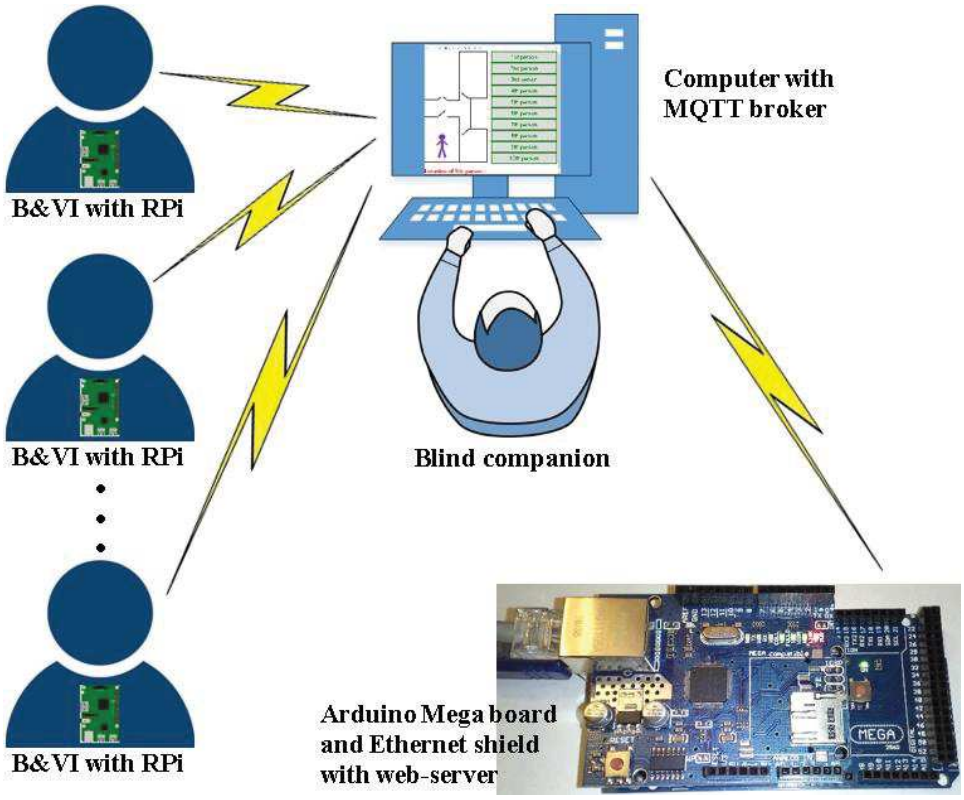
The presented soft-/hardware complex was successfully tested at the above-stated industrial facilities – the B&VI detected the unexpected obstacles on the distances of up to 1 m via the ultrasonic range sensor HC-SR04 on Raspberry Pi 3 B and the blind companion remotely localized the B&VI through the iBeacon fingerprinting, HTML dynamic website, and MQTT IoT protocol.

Figure 2: Raspberry Pi 3 B microcomputer with HC-SR04 sensor, 5 MP camera, headphones, and mobile power bank



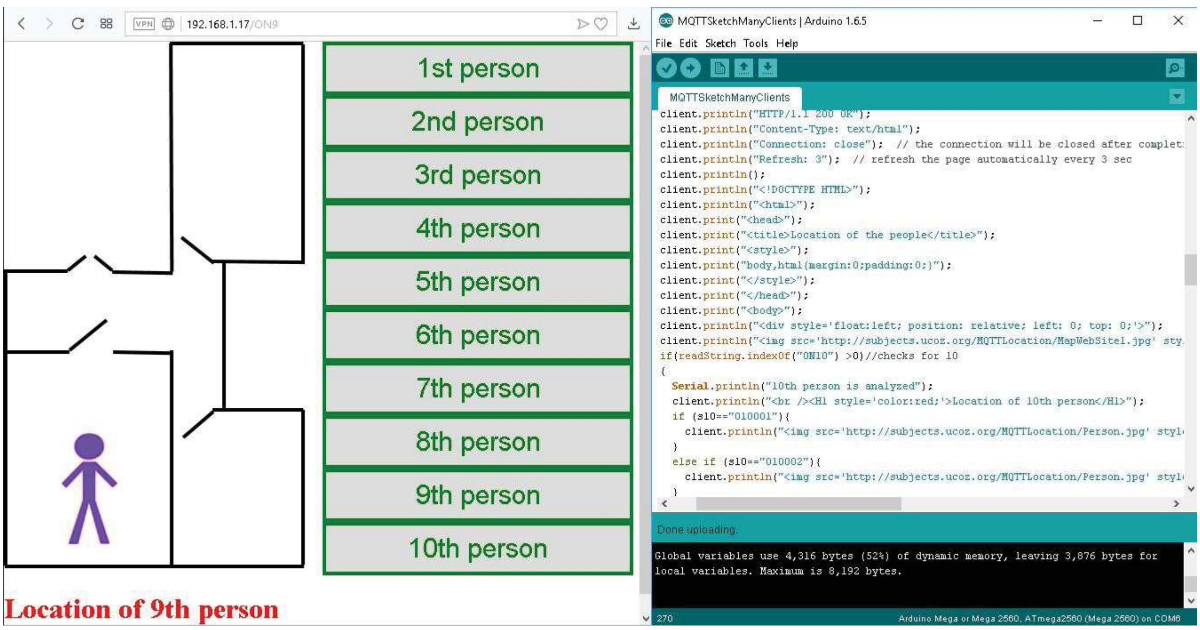
Source: the photo was taken by authors (2018)

Figure 3: Interaction between MQTT clients and broker (RPi stands for Raspberry Pi)



Source: the figure was designed and the photo was taken by authors (2018)

Figure 4: Screenshot of the HTML dynamic website with the B&VI location (on the left) and the Arduino sketch (on the right)



Source: the software was developed by authors (2018)

Our soft-/hardware complex satisfies the four-hospitality criterion – the remote localization and obstacle detection meet requirements to the accessibility, safety, and problem solving, the ability to apply other assistive technologies, e.g. face recognition, is the flexibility feature.

5. CONCLUSION

In this paper, a case study on the B&VI employment in the smart factories is discussed using Industry 4.0 technologies. An assistive device was developed to support the B&VI spatial cognition via the detection of unexpected obstacles in front of the B&VI on the distances of up to 1 m with ultrasonic range sensor HC-SR04 and Raspberry Pi 3 B based indoor localization of B&VI using the iBeacon RSSI fingerprinting, MQTT IoT protocol, and HTML dynamic website. The B&VI is advised on the presence of obstacles by headphones. The B&VI location information is transmitted to the blind companion. For the time being, the price of one kit for ten B&VI is about USD 700.

The experimental testbed is a small industrial facility of approximately 40 m^2 with three workrooms with one Bytereal iBeacon in each. Analysis of the iBeacon RSSI fingerprinting showed that the B&VI location is uniquely identified with the following rule: if RSSI of some iBeacon is greater than -65 dBm or greater than any other RSSI more than 11 dBm then the B&VI is in the workroom where this iBeacon is installed. The obstacle detection in front of the B&V is about 0.1 sec, which is quite acceptable for the slowly walking B&VI.

The presented soft-/hardware complex was successfully tested at the experimental testbed – the B&VI detect the unexpected obstacles on the distances of up to 1 m via the ultrasonic range sensor HC-SR04 on Raspberry Pi 3 B and the blind companion remotely localizes the B&VI through the iBeacon fingerprinting, HTML dynamic website, and MQTT IoT protocol.

Our soft-/hardware complex satisfies the four-hospitality criterion – the remote localization and obstacle detection meet requirements to the accessibility, safety, and problem solving, the ability to apply other assistive technologies, e.g. face recognition, is the flexibility feature.

The most likely prospect of the presented spatial cognition technology for the B&VI assistance in the Industry 4.0 enterprises is the integration of the developed soft-/hardware complex into other smart structures such as smart industrial transport / environment / governance.

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