The radio coverage monitoring by low-cost system based on SDR

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***Abstract* – The paper presents the design of a low-cost radio coverage monitoring system based on software defined radio. The main purpose of monitoring systems is real-time, low-cost measurement of coverage of radio signals in different environments. The monitoring systems are composed from a hardware and software part that is developed in the Matlab system. The main outputs from monitoring systems are a measured spectrum with computed characteristics. The software part includes a data viewer also developed in Matlab. The data viewer is used for projection of measured data in a base map, or received power in a timeline. The monitoring system was tested and evaluated. The measurements for different radio services (FM broadcast, 3G, LTE, DVB-T) are presented.**

***Keywords* –Monitoring system, software defined radio, coverage, RTL-SDR**

I. INTRODUCTION

The last two decades correspond to turbulent development in radio communication systems, especially from the point of view of the number of radio services. The increasing number of radio services increase demands on radio-monitoring systems. Radiomonitoring is gathering information about radiofrequency spectrum as a coverage of broadcasting services, supervision of maximal allocated power for individual transmitters, etc. In the market, there exists a lot of professional monitoring systems [1], [2], [3], that usually also include software for signal analysis, automatic classification of signals, demodulation-decoding schemes, etc. The disadvantages of professional monitoring systems are the high price, complexity of software and long training-time for human resources.

The main purpose of this research is developing a low-cost coverage monitoring system based on a software defined radio. This can be used for real-time monitoring of common radio services with future extension for localization of the source of unknown signals by the triangulation technique (as pirate broadcasting, identification of jamming, etc.). The main requirement for the developed system was low cost, wide frequency band, and universal software (easy change for other type of Software Defined Radio - SDR). The biggest advantages of the SDR is the low price, that can vary from 20 up to 1000 USD. The high variability in the prices for SDR is caused by differences in parameters of the SDR (frequency range, sampling frequency and resolution in amplitude). The table of selected compared SDRs is shown in the Table 1. From the point of view of price, the best option is RTL-SDR radio that we used in actual solution. From the point of view of SDR parameters, USRP from Ettus research is the best.

TABLE I. LIST OF SELECTED SDR

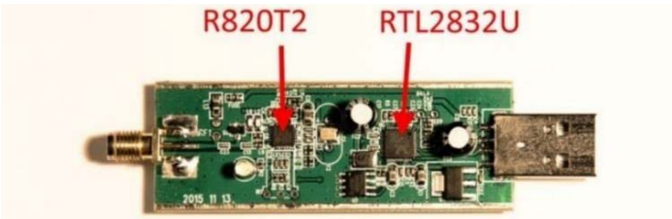
Product	Freq. range [MHz]	Bandwidth [MHz]	ADC res. [Bits]	Price [USD]
RTL-SDR	24-1766	3,2	8	20
Airspy Mini	24-1750	6	12	99
SDRPlay	0,01-2000	10	12	130
Airspy R2	24-1750	10	12	169
HackRF One	1-6000	20	8	299
LimeSDR	0,1-3800	61,44	12	299
BladeRF	300-3800	28	12	420
USRP B200	70-6000	56	12	800

II. MONITORING SYSTEM BASED ON RTL-SDR

The actual designed coverage monitoring system is based on RTL-SDR [4]. The SDR is the cheapest variant where the principle of the designed monitoring system was verified. The parameters of the RTL-SDR are presented in Table II. The design of the SDR is shown in Fig.1.

RTL-SDR Parameters	Values
Demodulator	Realtek RTL2832
Receiver	Realtek R820T2
Frequency range	25-1766 MHz
Maximal sampling frequency	2,4 MS/s, theoretical 3,2 MS/s
Bandwidth	3,2 MHz
Resolution of the ADC	7 b, theoretical 8 b
Input impedance	75 Ω
Maximal power of received signal	+10 dBm
Stability of the oscillater	1 PPM
Connectivity	USB 2.0

Figure 1. The design of RTL-SDR

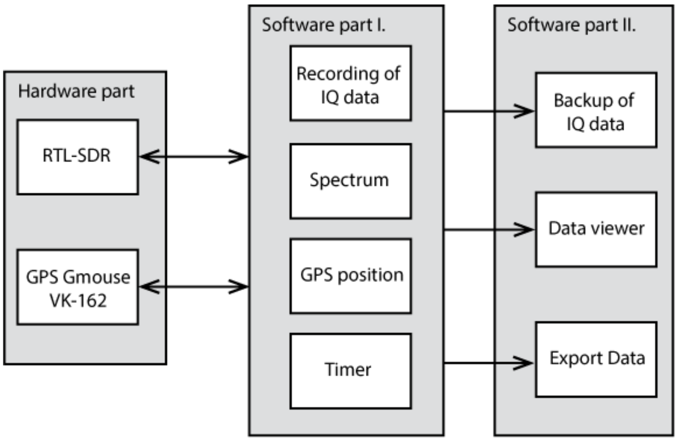


The documented application of the RTL-SDR usage are

- I/Q data recorder [5]
- Decoding of the TETRA [6], [7]
- Decoding of the meteorological satellites NOAA [8]
- Decoding of the text message in GSM network [9]
- Decoding of the ADS-B, mode S, etc. [10]

The block scheme of the monitoring system is presented in Fig. 2. The RTL-SDR and GPS Gmouse VK-162 present the hardware part of the monitoring system (except antennas connected to RTL-SDR - description below). The software part is developed in Matlab software [16] and compiled to a standalone program, independent of developed software (after installing Matlab runtime).

Figure 2. The block scheme of monitoring system



The hardware part of the monitoring system is (1) RTL-SDR, (2) GPS receiver GPS Gmouse VK-162 [11] and (3) computational unit with installed software. The GPS receiver has parameters (chip Ublox 6010/7020, accuracy 5m, timing accuracy 1µs, reference coordinate system WGS-84, tracking sensitivity -160 dBm and acquisition sensitivity -146 dBm, USB). For the computational unit, Dell 11z Touch was used. For outdoor measurement notebook with touch screen or tablet is recommended. Hardware parts (1) and (2) are connected by USB to a computational unit with developed software.

The requirements for software part was, easy control of base radiomonitoring system parameters, recording of I/Q data from receiver connected with data from GPS receiver, and visual representation of measured data in maps. The application is divided to two base parts. The first part is related to outdoor measurement and recording of data, and second part is related to the visualization of measured data. Both software can be used independently. The data measurement is based on measurement of received power of the received signal by RTL-SDR. Information about position comes from the GPS receiver.

The screenshots from the recording part of software are shown in Fig. 3. In the status panel, is shown an indication of the connected RTL-SDR, and GPS receiver with confirmation of GPS signal availability. The data recording can be done also without a GPS receiver, but this is suitable only for monitoring from a static place (without changing of position). The main graphic outputs are spectrum of signal (with bandwidth correspond to the maximal bandwidth of RTL-SDR that is 2,4 MHz), and detail of selected spectrum (based on bandwidth in measurement settings and timeline of power of received signal. The user can change input parameters central frequency, bandwidth of recorded signal (10-2200 kHz), simple timer (how many measurements per second), gain of RTL-SDR, backup savings (after how many recorded data will partial results be saved in a csv file), and weighting function (rectangular, Hanning, Blackmann, Hamming window). The function of the timer is selecting a suitable value of measurements per setting that can be find out by the “Calibrate Timer”. The function of timer is selection of suitable value of measurements per setting that can be find out by “Calibrate Timer”. The Measuring part includes information about the “highest” peak in the selected spectrum, band mean value, whole spectrum mean value, timeline samples and sample count.

Figure 3. The block scheme of monitoring system

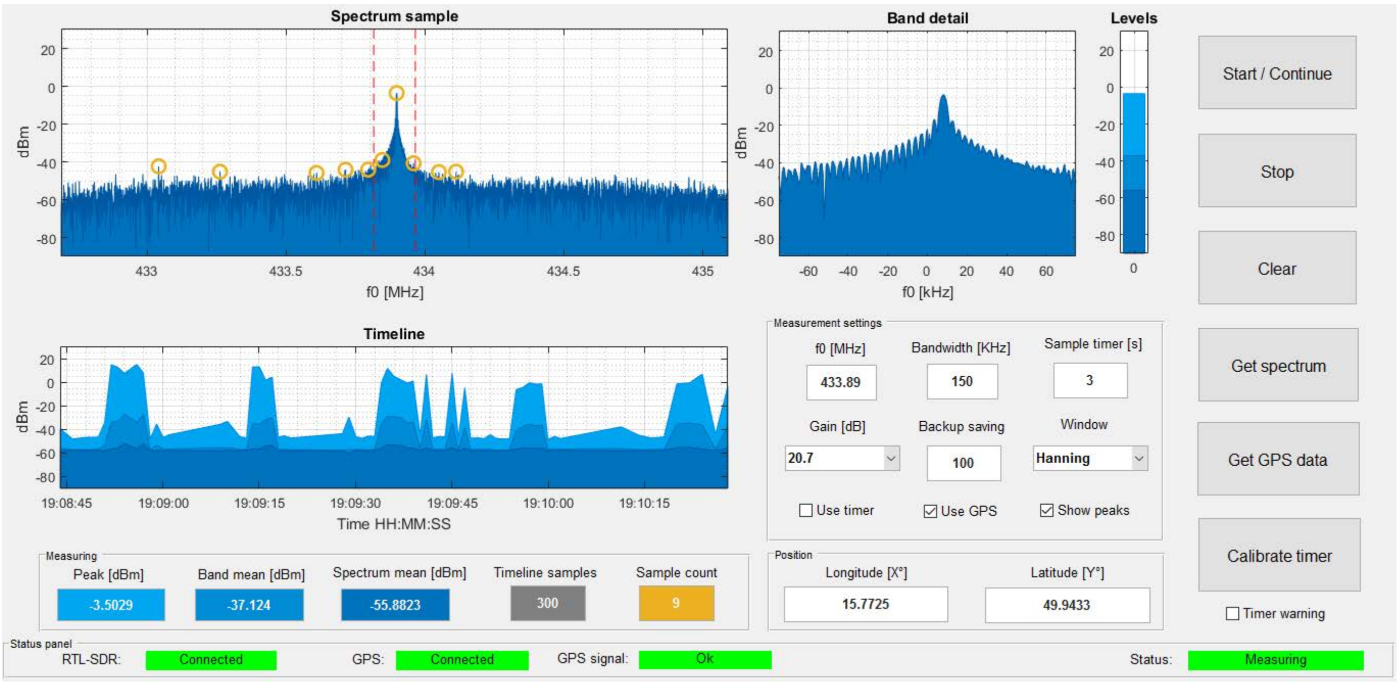
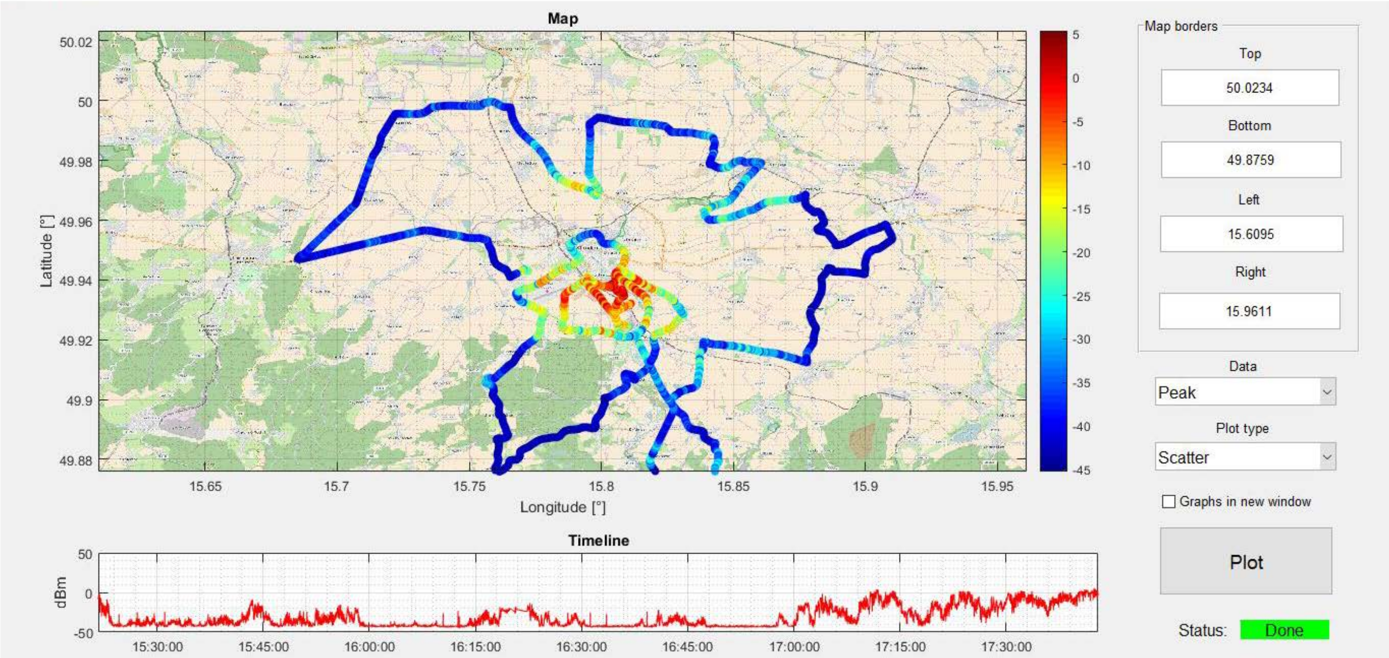


Figure 4. Data viewer



The recorded data are automatically saved in csv file, where every row corresponds to one measurement that includes information about the maximum value of the spectra in selected bandwidth [dBm], average value in selected bandwidth [dBm], GPS data, and time of data recording.

The data viewer (second part of software) is shown in Fig. 4. The data viewer function is visualization and representation of recorded data on maps where maps from OpenStreetMap [12] is used. The „curve" shown in the map represents recorded data and map coordination system. The data can be represented by scatter plot, by signal strength map (Fig. 7, 8, 9) or by representation of the measured data in a timeline that is suitable for monitoring of signals that are variable in time.

For the monitoring of different frequency bands, different antennas are used. For UHF (140-148 MHz) and VHF (430-450 MHz) band is used Hoxin VUM-201 [13]. Antenna Hoxin SRH-519 [14] is used for frequency band 0,5 MHz to 1300 MHz, antenna for DVB-T (base antenna with RTL-SDR), antenna C37 [15] for LTE800 and UMTS 2100 services that works in bands (791-894 MHz, and 1,92-2,17 GHz). In Fig. 5a, an example of use of low-cost monitoring system for handheld usage is presented. In Fig 5b, a usage system for car measurement is presented. The price for monitoring systems includes all antennas which do not exceed 50 EUR (excluding PC).

III. Measurement with Monitoring System

The validation of the monitoring system was done in Zagreb, Croatia. The selected area is bordered by four streets. Ilica is in the north of the area, Ulica Andrije Hebranga is in the south of the area, Savska cesta is in the west of the area and Ulica Junija Palmotića is the east of the area. The monitoring area is shown in Fig. 6.

Figure 5. Real-time monitoring system in practice

The measured services are

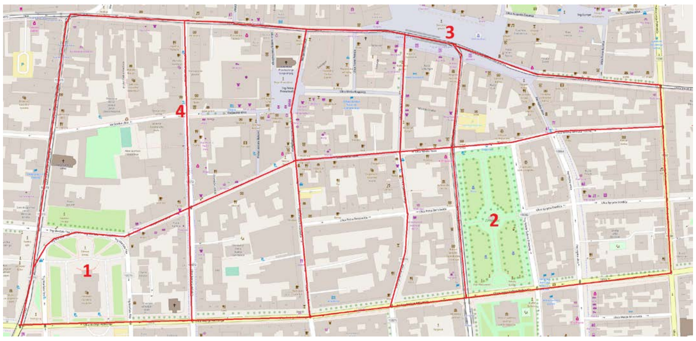
(1) FM radio broadcasting – Radio 101 [18] with parameters (central frequency 101 MHz, bandwidth 150 kHz, gain of receiver 37,2 dB),

(2) DVB-T broadcasting with parameters (central frequency 506 MHz, bandwidth 500 kHz, gain of receiver 37,2 dB,

(3) LTE 800 downlink with parameters (central frequency 792 MHz, bandwidth 500 kHz, gain of receiver 37,2 dB,

(4) LTE800 operator T-mobile – train corridor Přelouč – Prague, Czech Republic (central frequency 792,8 MHz, bandwidth 500 kHz, gain 29,7 dB).

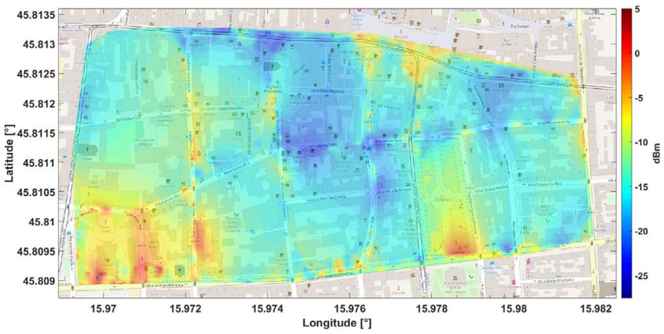
Figure 6. The monitoring area



The area of power was calculated from the measured samples by interpolation in the defined measurement area. It was used the Natural neighbor interpolation. This area of power is called strength map.

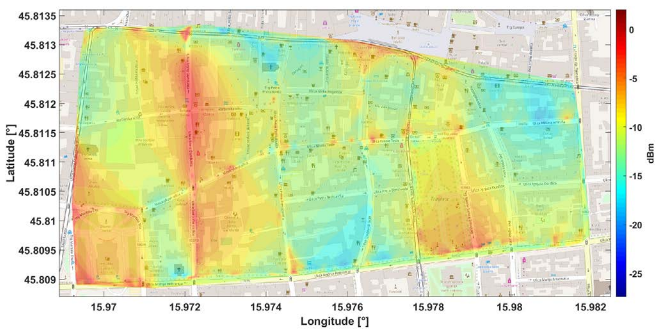
The first measurement was focused on FM radio broadcast (Radio101). The strength map of this service is shown in Fig.7.

Figure 7. The strength map of FM broadcasting



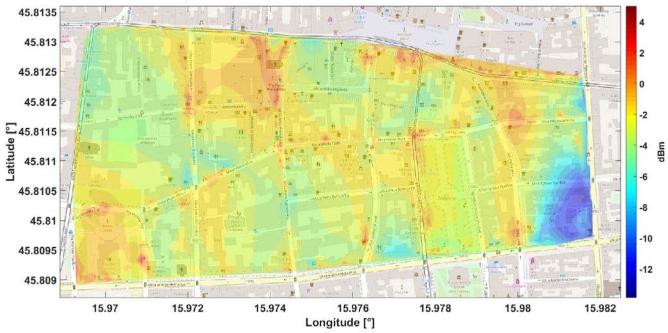
The second measurement was focused on Digital Video Broadcasting – Terrestrial (DVB-T). The strength map of DVB-T is shown in Fig. 8.

Figure 8. The strength map of DVB-T broadcasting



The third measurement was focused on a LTE 800 downlink of VIP operator. This is reason why this service wasn't measured. The LTE 1800 service was not measured due to frequency limitation of RTL-SDR. The strength map of LTE 800 downlink is shown in Fig. 9.

Figure 9. The strength map of LTE800 downlink



It can be seen, that the strongest signals for all our measured services are near the Croatian National Theater (1), Park Zrinajevac (2), Ban Josip Jelacic Square (3) and Gunduliceva street (4). These numbers of locations in parentheses are shown their positions in Fig. 6. The main reason is it that these areas are in open air. Therefore, there is no such loss of signal strength. The power of these measurements is in an interval $\langle -25;5 \rangle \, dBm$.

The measurement of LTE on train corridor Přelouč-Pardubice, Czech Republic is shown in Fig. 10 (strength map), and in Fig 11. (timeline). The average attenuation of the train carriage is about 45 dB [17]. From the measurement, it follows that best coverage of service is only around cities. The problematic parts are forested and uninhabited areas.

Figure 10. The strength map of LTE800 downlink [19]

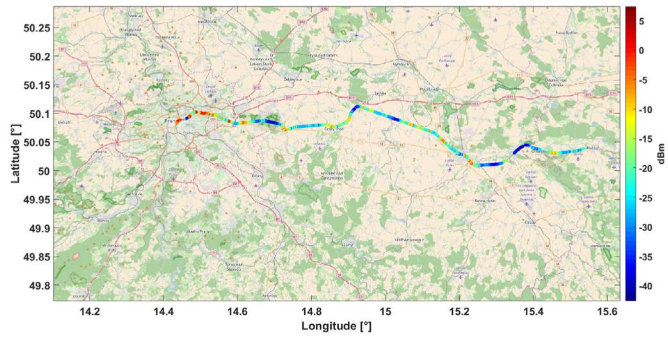
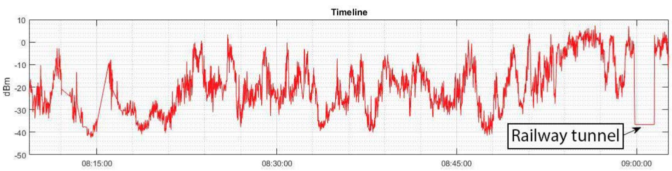


Figure 11. The timeline of LTE800 downlink [19]



IV. Conclusion

The low-cost monitoring system based on RTL-SDR was successfully developed. In the first stage, research of the available SDR was made from different price margins and different RTL-SDRs. The developed software from the point of view of using different SDR is universal. The only change is rewriting the script for communication between different SDR and Matlab (that is very often available on side of manufacturer of SDR). The rest of the software is completely independent of used SDR.

The monitoring system was successfully validated from the point of view of measurement of signal strength (power) for different broadcast services such as FM broadcasting, DVB-T broadcasting, and LTE800 downlink. All this measurement was done in Zagreb center, Croatia. The last measurement was done in LTE 800 downlink in the train corridor in Czech Republic.

The main advantages of the developed monitoring system are price, size, mobility and the ability to connect to any laptop that is based on a Windows platform.

In the future, usage of different SDR as a USRP, Lime is planned for monitoring of different services. The next plan is an extension of the function of the developed software.

Acknowledgment

This paper was supported by the internal grant from the University of Pardubice SGS_2017_026 and financially supported by the project FV10484 from the Ministry of Industry and Trade of the Czech Republic.

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