

Modern Software Defined Radar (SDR) Technology and Its Trends

Young-Kil Kwag* · Jung-Soo Jung · In-Sang Woo · Myeong-Seok Park

Abstract

Software defined radar (SDR) is a multi-purpose radar system where most of the hardware processing is performed by software. This paper introduces a concept and technology trends of software defined radar, and addresses the advantages and limitations of the current SDR radar systems. For the advanced SDR concept, the KAU SDR Model (KSM) is presented for the multimode and multiband radar system operating in S-, X-, and K-bands. This SDR consists of a replaceable multiband antenna and RF hardware, common digital processor module with multimode, and open software platform based on MATLAB and LabVIEW. The new concept of the SDR radar can be useful in various applications of the education, traffic monitoring and safety, security, and surveillance depending on the various radar environments.

Key Words: Multi-Band SDR, Multi-Mode SDR, Open Software Platform, Software Defined Radar (SDR).

I. INTRODUCTION

Since radar is an electromagnetic sensor, its inherent capability is in all-weather and day or night operation, and thus its application is recently closing to our living environments, such as medical imaging, as well as urban radar for security and safety. As the modern radar technology has rapidly been grown, it has been becoming feasible to be easily implemented for the multifunctional and high performance radar. However, conventional fixed purpose radar system development still requires long development cycle and high cost because of the dedicated application in a certain radar environments. This makes the radar development difficult to the users' applications for multi-purpose, high performance, small size, and low cost. In order to overcome these constraints, software defined radar (SDR) was introduced for the multifunctional system where most of the hardware processing, like waveform generation and up and

down conversion are performed by software. Software defined radar has many advantages such as a multipurpose system, the ability to re-using the hardware, ease of implementation of signal processing algorithms, faster development and cost reduction.

Early SDR was developed using field programmable gate array (FPGA) and a digital signal processor (DSP) for target distance detection [1, 2]. The Universal Software Radio Peripheral (USRP) which is developed at a low cost is one of the most well-known SDR platforms. The first application of USRP was applied to perform target detection [3]. However the USB interface between the host PC and processor module limit the system performance [4-7]. The most problems in development of SDR platform are related to narrow bandwidth and low speed interface.

This paper presents a broad overview of software defined radars. The concept and technology trends are presented in

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School of Electronics and Telecommunication Engineering, Radar Research Institute, Korea Aerospace University, Goyang, Korea.

*Corresponding Author: Young-Kil Kwag (e-mail: ykwag@kau.ac.kr)

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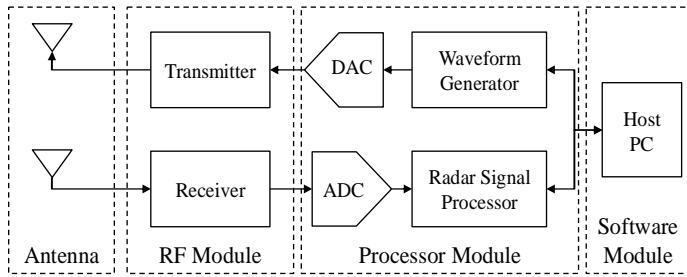


Fig. 1. Basic concept of software defined radar (SDR) system.

Section II. The SDR system which is being designed by Korea Aerospace University is discussed in Section III. The applications of SDR are explained in Section IV, and finally, conclusions are provided in Section V.

II. OVERVIEW OF THE SOFTWARE DEFINED RADAR SYSTEM

1. Concept of Software Defined Radar

The SDR system consists of a general RF module and a reconfigurable software module. Radar components, such as mixers, filters, modulators, demodulators, and detectors, typically have been constructed in the hardware. The components are implemented using software on a PC, DSP or FPGA in SDR. The basic construction of SDR is presented in Fig. 1.

2. Technology Trend of SDR

The SDR system can be applied to various areas so that advanced countries are studying and developing the system. A technology trend of the SDR system in each country is summarized in Table 1.

2.1 America

Rosler et al. [8] demonstrated a joint radar-communication system which uses wideband digital communication signals to simultaneously interrogate a scene as radar while communicating range-Doppler maps resulting from previous interrogations. Frankford et al. [9] greatly simplified the evaluation of MIMO and adaptive waveform techniques through the use of the OSU SDR, a flexible self-developed radar platform. Furthermore, this radar operated at two frequencies simultaneously, allowing for dual frequency human measurements [10]. Garmatyuk et al. [2] implemented orthogonal frequency-division multiplexing (OFDM) signal coding and system architecture to achieve radar and data communication functionalities. Therefore, the resultant system could be used for range measurements, radar imaging, and data communications. Ancortek Inc. investigated the use of SDR to analyze the micro-Doppler signatures in two kinds of platforms, USRP-based SDR and FPGA-based

Table 1. Summary of SDR trend

Country	Research trend
America	- Joint radar-communication system
	- MIMO and adaptive waveform techniques
	- OFDM based multifunction radar
	- Analysis of micro-Doppler signatures between USRP-based and FPGA-based SDR
	- Hybrid radar scheme with continuous wave frequency modulation and pseudo-random code pulse techniques
EU	- USRP based L-band SDR system
	- Airborne SDR system
	- Multi-purpose SDR system which combined radar and a jammer function
	- USRP based C-band SAR system
	- USRP based OFDM radar system
Other countries	- Passive radar using SDR technology in a Wi-Fi network
	- Prototypes of ground penetrating radar (GPR) using SDR technology
	- Analysis method of human movement parameters using USRP
	- Study of USRP based weather radar
	- Multi-band multi-beam passive bistatic radar using USRPs and array antennas
- USRP based SAR system	
- USRP based passive radar system	
- USRP based OFDM radar	

MIMO=multiple-input and multiple-output, OFDM=orthogonal frequency-division multiplexing, USRP=Universal Software Radio Peripheral, FPGA=field programmable gate array, SDR=software defined radar, SAR=synthetic aperture radar.

SDR. They tested each platform in CW and FMCW modes to study micro-Doppler characteristics of human gaiting as well as helicopter rotor blades [11].

In Canada, Zhang et al. [1] proposed a hybrid radar scheme with continuous wave frequency modulation and pseudo-random code pulse techniques. The system showed the ability to obtain high precision information concerning the velocity of a vehicle, the distance, the direction and other information useful to improve the security in the automotive field.

2.2 EU

In Italia, Costanzo et al. [12] adopted a USRP to design a high resolution L-Band SDR system, which was tested which was tested in outdoors and showed accurately the correct target position with the predicted slant-range resolution equal to 6 m. They also discussed the synchronization issues existing between a received and a transmitted signal when a USRP is considered [3]. They proposed a multiband SDR based on the OFDM technique for the accurate detection of soil discontinuities, taking into account also the dispersive behavior of media [13].

In Poland, the maritime patrol radar was made with an airborne SDR system that could switch between different modes. The algorithm was loaded on a FPGA by means of a PC [14], and a multi-purpose RF system which combined radar and a jammer function on the same hardware was demonstrated [15]. Lately, Gromek et al. [16] tried a concept of USRP as a hardware platform for FMCW synthetic aperture radar in C-band.

In Germany, Braun et al. [6] presented a measurement testbed for OFDM radar which uses USRPs as the front-ends. The resultant system required little power and could thus be easily installed in vehicles to perform measurements for car-to-car or car-to-infrastructure applications. In the UK, Woodbridge et al. [17] reported the development of wireless passive radar using SDR technology in a Wi-Fi network.

2.3 Other Countries

In Australia, Ralston et al. [18] explored the potential of SDR technology to provide flexible and low-cost subsurface radar prototypes for the ground penetrating radar (GPR) community. In Norway, a low-cost radar platform was designed to extract human movement parameters in the presence of indoor multipath and clutter. This platform offered the opportunity of realizing low-cost experiments at an expedited pace and low budget [19]. In Indonesia, Prasetyadi et al. [20] proposed a simple delay compensation system to solve USRP's additional delay problem by employing a constant signal transmitted before the FMCW signal. Moreover GNU Radio based software defined FMCW radar was studied for weather surveillance application [21]. In Saudi Arabia, the design and

development of multi-band multi-beam software defined passive bistatic radar were demonstrated. This system could operate at any carrier frequency, bandwidth and signals over a large frequency spectrum up to 6 GHz, with transmitters of opportunity at spatially-diverse locations [22]. In India, an attempt was made to explore the means to use a SDR to implement a basic radar system and then synthetic aperture radar [4]. In South Africa, a prototype passive radar system that utilized FM radio transmitters for target detection was presented [23]. In Singapore, OFDM radar for open doorway detection was implemented using an USRP [24].

III. MULTI-BAND AND MULTI-MODE SDR RADAR

The project, SDR Radar Sensor Platform Development, is in progress at Korea Aerospace University (KAU). The main goal is the development of the multiband and multimode SDR platform in ISM bands. The KAU SDR Model (KSM) consists of replaceable antenna and RF modules at multiband of S-, X-, and K-band, signal processor module, and software module as shown in Fig. 2. The RF modules are developed to enable the replacement of each operation frequency. RF modules modulate analog signals and radiate the RF signals through the antennas. The received echoes are transferred to a signal processor module through an RF module. The processor module generates various waveforms, such as continuous waves (CW), frequency-modulated continuous wave (FMCW), pulse, and linear frequency modulation (LFM) pulse. These waves are transferred from the computer module and sent to the RF module through a digital-analog converter (DAC). The selection functions of waveforms lead to perform multimode SDR. The host PC performs the post processing, such as detection and tracking, and displays results after data are processed in the signal processor module. The host PC can be used to control the hardware system and waveform settings. The software library provides support for pushing and pulling data to and from the signal processor, for changing the waveform and/or parameters of the SDR and for performing radar signal processing. The key specification of the system is presented in Table 2.

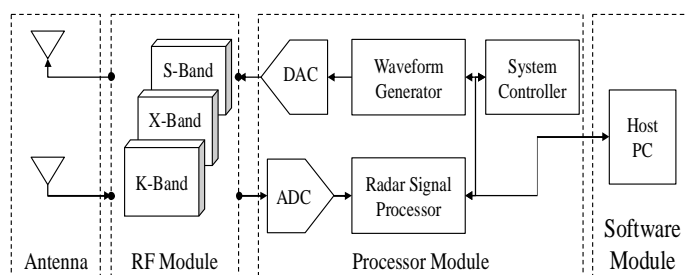


Fig. 2. Block diagram of KSM software defined radar (SDR) system.

Table 2. KAU SDR model (KSM) system specification

Parameter	S-band	X-band	K-band
Frequency (GHz)	2.4	10.5	24.05
EIRP (mW)	10	25	100
Bandwidth (MHz)	25	50	150
Resolution (m)	6	3	1
Range (m)	30	40	100
Waveform	CW/FMCW/Pulse/LFM Pulse		
Interface	Gigabit Ethernet, Wi-Fi		

KAU=Korea Aerospace University, SDR=software defined radar, EIPR=equivalent isotropically radiated power, CW=continuous wave, FMCW=frequency modulated continuous wave, LFM=linear frequency modulation.

1. Antenna

KSM is a bistatic radar system. The various types of antennas such as horn, patch, and substrate integrated waveguide are being designed and will be developed in S-, X-, and K-bands. It will be used to apply in broad fields.

2. RF Module

The RF module consists of a transmitter and a receiver and three models will be developed to operation in S-, X-, and K-bands. The transmitter converts a waveform from intermediate frequency (IF) to RF, and transfers to the antenna through the power amplifier. The receiver amplifies low noise of the echo signal from the antenna, and performs down-conversion. Fig. 3 shows a block diagram of the RF module in the SDR system. Local frequencies use the same reference clock because of system coherence. The controllable parameters of the software module are transmitting power, receiver gain, and pulse repetition frequency.

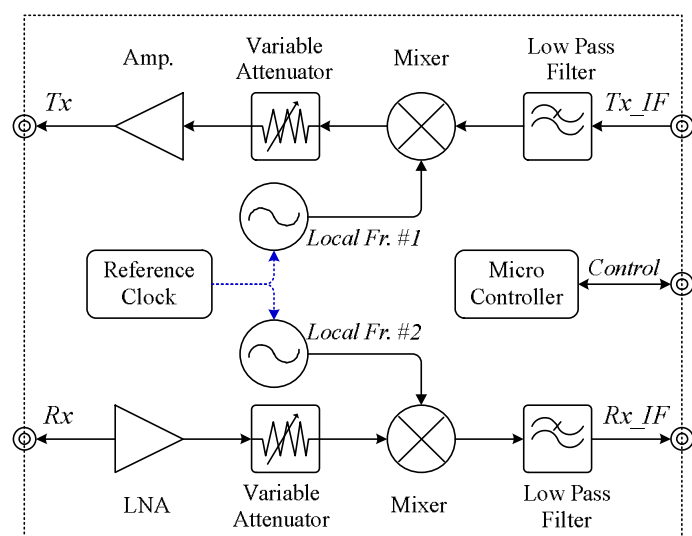


Fig. 3. Block diagram of RF module in Korea Aerospace University (KAU) software defined radar (SDR).

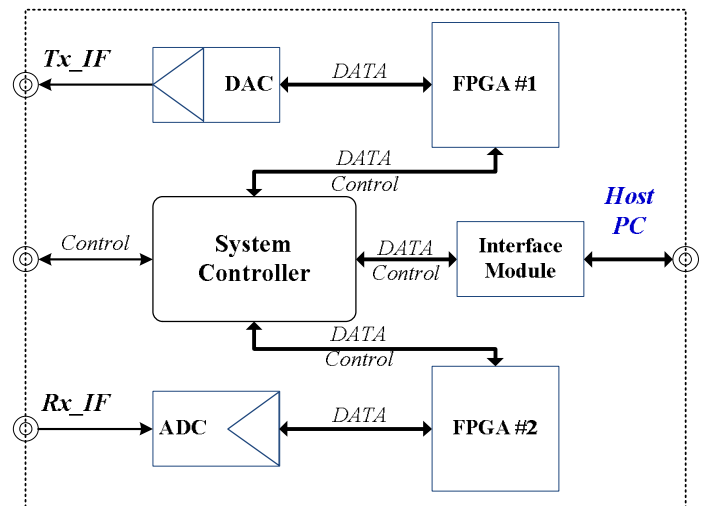


Fig. 4. Block diagram of processor module in Korea Aerospace University (KAU) software defined radar (SDR).

3. Processor Module

The major missions of the processor module as shown in Fig. 4 are waveform generation, signal processing, and data transmission. Waveform generation is performed by FPGA and DAC. The type of waveform is controlled by the host computer. FPGA and DSP process the digital converted signals by analog-to-digital convertor (ADC). Digital down conversion and Hilbert transformation are the basic procedure. Also, some pre-processing, like as pulse compression and de-chirp, will be performed according to waveform. Algorithms and procedures are adjusted by the host computer. The various types of data are generated in the processor module. Raw data can be saved for algorithm evaluation, and display data will be transferred to the host computer. The data in the processing steps can be delivered by the system controller as well. The processor module is connected to the host computer via Gigabit Ethernet interface.

4. Software Module

The software module was developed based on open application programming interface (API) by applying MATLAB and LabVIEW as shown in Fig. 5. The open software module consists of a hardware interface, service interface, library connection daemon, and four software applications. The HW interface is used for data acquisition and processing of the control signal. The service interface provides information of application software and HW interface, control, and displays API function. Library server connects commercial tool like as MATLAB and LabVIEW with processor module. The application software, such as education, traffic, security, and monitoring software, is a separate software platform for application of SDR. Since the signal processing simulates algorithms, the software libraries support results in a test on which algorithms for raw data can be evaluated. The processed results can be used to enhance the performance of the signal processing algorithms.

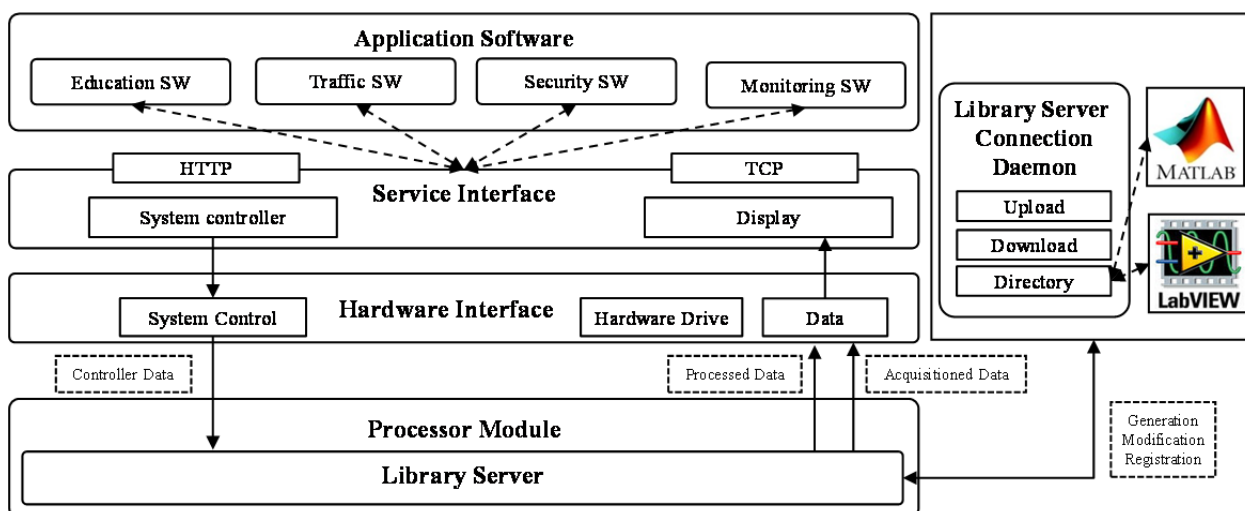


Fig. 5. Block diagram of software module in Korea Aerospace University (KAU) software defined radar (SDR).

IV. APPLICATION OF SDR

SDR has many advantages such as the possibility to create multipurpose radar, the possibility to re-use the same hardware, an easier implementation of advanced signal processing algorithms, faster development and a reduced cost. Based on the above potential of SDR, its application areas in Table 3 are follows: human motion detection, automotive navigation, GPR, and educational tools are considered near-range applications. Military multi-function radar, a passive coherent location (PCL), an aerial observation using SAR, and weather surveillance are considered far-range applications.

In a human motion detection area, SDR can be exploited as the micro-Doppler radar system for detecting and analyzing the various human gestures. Such a sensor system with a compact size can be accepted as a competitive technology in the camera and IR technology-centered sensor market, due to the unobtrusive detection and low privacy risk. This system is used to check the health conditions of the elderly and prevent falls and other accidents by analyzing their activity profile in the healthcare and wellness domain [19].

Table 3. SDR system applications

	Application area
Near-range application	Security radar
	Automotive radar
	Ground penetrating radar
	Educational radar tool
Far-range application	Surveillance radar
	Airborne SAR
	Weather radar
	Military multifunction radar

In an automotive navigation application, SDR can realize a hybrid radar scheme by the combination of radar and communication function. The two functions can be carried out in turns by switching modes or concurrently through a special waveform, such as OFDM [6, 23].

In a GPR context, SDR is applicable as multiband radar for accurate detection. For the multiband operation, the SDR concept provides strong advantages with respect to classical radars, due to the easy software implementation of all required hardware modules and the easier integration into a compact system of signal processing operations [13].

In an educational tool area, SDR can be utilized as an effective teaching tool for students or trainees. From the viewpoint of low cost and high flexibility, SDR systems will be introduced as a practice tool in radar engineering curriculums, for example as the role of SDR technology in DSP and communication theory curriculum [25].

In a PCL area, SDR is used for realizing passive radars. Even though each illuminator of opportunity has different waveforms, SDR can reconfigure the receiver system to the favorable signal in each radio environment. The illuminators of opportunity can be divided into two main classes: analogue signal like FM radio, analogue TV or digital signal like DVB-T, UMTS, and Wi-Fi [21].

In an aerial observation area, SAR system can be developed through the SDR technology. This system can easily be mounted in a private setting by hobbyists or even by academics on small aircrafts, due to the compact size and light weight [16]. In a military equipment area, SDR enables the multifunction RF payload to be installed in limited-space aircrafts, especially UAVs [26]. They include detection mode like GMTI, SAR, ISAR, weather surveillance, communication mode, and EW mode. In a weather surveillance area, SDR has cost reduction merits for building a weather radar network [13].

V. CONCLUSION

This paper describes the overall concept and trend of software defined radar technology. For the advancement concept, the KSM is presented with the replaceable RF hardware, a common digital processor, radar processing algorithm library and open software platform. This multiband and multimode SDR radar can be applicable to the radar training education, traffic monitoring and safety, security, and surveillance.

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Young-Kil Kwag



received his B.S. from the National Aviation University in 1976, his M.S. in Electronics Engineering from Korea Advanced Institute of Science (KAIST), Korea in 1981, and his Ph.D. in Electrical Engineering from Ohio University, Ohio, USA in 1987, respectively. He is a full professor at the School of Electronics and Telecomm. Eng., and Director of Radar Research Institute, Korea Aerospace University (KAU). He was the General Chair of APSAR 2011 (www.apsar2011.org) in Seoul, Korea. Prior to joining the university in 2001, he worked for: the Agency for Defense Development (ADD), Korea as a Division Head, Principal Researcher, and Project Manager with over 25 years in the field of radar systems and radar signal processing, and spaceborne SAR systems. From 1997 to 1999, he was a ADD-MMS joint project manager at the Matra Marconi Space (MMS), UK, for the spaceborne synthetic aperture radar (SAR) system development. He was the founding chairman of the Korea Radar Society of KEES, and also he was the founding chairman of the Korea Aerospace Electronics Society of KSAS. He is currently holds the position of chairman at the IEEE AESS Seoul Chapter. Since 1990, he has been serving as co-chair, session chair, reviewer and referee of the international radar conference of IEEE/IET, AESS, EUSAR, APSAR. He was a visiting professor at Oxford University in the UK from Sept. 2007 to Aug. 2008. Since 2013, he has been appointed as a senior member of the Big Science Committee in the National Science & Technology Council, Ministry of Future and Science, Korea. He is a senior member of IEEE, and he is the honor member of Pi Kappa Pi, Eta Kappa Nu, Pi Kappa Pi. He has been honored by Marquis Who's Who, American Biographic Institute (ABI), and Cambridge Biographic Institute (CBI). His areas of interest include radar system design, radar signal processing, synthetic aperture radar imaging, collision avoidance radar, adaptive array and interference suppression algorithms.

Jung-Soo Jung



received his B.S. and M.S. degree in Avionics from Korea Aerospace University (KAU), Seoul, Korea, in 2007 and 2009, respectively. He has been pursuing a Ph.D. in Avionics at KAU since 2011. From 2009 to 2010, he was a Research Assistant with Korea Institute of Ocean Science & Technology (KIOST). His research interest includes radar and SAR systems and radar signal processing, radar detection and numerical analysis.

received his B.S. and M.S. degree in Avionics from Korea Aerospace University (KAU), Seoul, Korea, in 2007 and 2009, respectively. He has been pursuing a Ph.D. in Avionics at KAU since 2011. From 2009 to 2010, he was a Research Assistant with Korea Institute of Ocean Science & Technology (KIOST). His research interest includes radar and SAR systems and radar signal processing, radar detection and numerical analysis.

In-Sang Woo



received a B.S. in Electronics and an M.S. in Molecular Science Technology from Ajou University, Suwon, Korea, in 2001 and 2009, respectively. He has been pursuing his M.S. degree in Avionics at Korea Aerospace University (KAU) since 2013. From 2009 to 2012, he was an antenna engineer in Dongnam Int. His research interests include radar system and radar signal processing, and antenna design.

received a B.S. in Electronics and an M.S. in Molecular Science Technology from Ajou University, Suwon, Korea, in 2001 and 2009, respectively. He has been pursuing his M.S. degree in Avionics at Korea Aerospace University (KAU) since 2013. From 2009 to 2012, he was an antenna engineer in Dongnam Int. His research interests include radar system and radar signal processing, and antenna design.

Myeong-Seok Park



received B.S. from Hankyong National University in 1999, the M.S. in electronics engineering from Sungkyunkwan University, Korea in 2002. He is a senior research engineer of Radar Research Institute, Korea Aerospace University (KAU). From 2002 to 2007 he worked at the STX Engine Co., Ltd. as a research engineer. From 2008 to 2013 he worked at the Telex Co., Ltd. as a senior research engineer.

His areas of interest include the radar system design, radar transmitter and instrument landing system (ILS).