Cognitive radar control system using machine learning

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Abstract. Cognitive radars are systems based on the percept-action cycle of cognition that sense the environment, extract relevant target and background information from it, and then adapt the radar sensor to optimally meet the needs of its mission according to the desired target. The aim of the study is to determine the options for using the cognitive approach to improve the performance of the radar system. The study results show the criteria by which a radar should be defined as cognitive. In addition, our task was to propose machine learning methods based on artificial neural networks for the problem of radar resource allocation.

1. Introduction
The ability to adapt to a complex and changeable radar environment while observing fast-moving objects requires the development of multifunctional multichannel radar stations (MR) with an active phased antenna array. Electronic scanning in two planes and a digital information processing system allow for continuous observation of space, detection, recognition, guidance of air defense means and tracking of targets in real time. Algorithmic software that solves the problems of processing radar objects is one of the most complex elements of MR.

MF software includes components such as: system operation control, beamforming, spectral processing, detection of radar objects and estimation of their parameters, trajectory processing of incoming information, recognition of objects and situations, analysis of the emerging radar situation and adaptation to the conditions of the system functioning. The continuing improvement of the tactical and technical characteristics of air attack weapons necessitates the development and application of organizational and technical control systems with cognitive properties.

2. Cognitive radar
CR [1] is a radio engineering system that uses technology to enable the system to gain knowledge about: the operating environment; geographic data; resource allocation algorithms; internal state; dynamically and autonomously change operating parameters and protocols. And execute commands in accordance with the knowledge gained, in order to achieve predetermined goals and learn from the results obtained.

In contrast to adaptive radar, the CR learns to adapt operating and processing parameters and can schedule work for longer periods of time. In figure 1 presents the concept of a cognitive radio system [2], and shows information transfer between RC functions. The environment includes received radar information, commands from other technical systems and the radar operator. Internal state, contains information about the rules for allocating resources between radar tasks and radar signals parameters.
Figure 1. The concept of the cognitive radio system.

CR receives information about the environment and internal state, transforms information into knowledge and applies them in the process of learning and adaptation. During the learning process, information is compared with the results of previous decisions and accumulated to optimize future decision making.

For a continuous learning process, information from previously made decisions is used, provided that the decisions were effective in the process of interacting with the environment. Several training methods can be implemented, for example, by generating new rules. In the future, information after training is involved in obtaining new knowledge. The learning process can be simplified by loading a priori knowledge specified by the developer and using software with new logic for future decisions. Decisions are made and corrected using algorithms and strategies based on knowledge about the environment and the internal state of the cognitive radio system and information obtained in the learning process and past decisions and the degree of their success.

2.1. Perception-action cycle
CR and the environment represent a closed feedback system. CR initiates the necessary action, for example, the emission of a probe signal. The signal at the receiver input is a mix of the true signal and various noise, interference, clutter and reflections. The received signal is analyzed by a signal processing system to extract environmental data, which is combined with a priori knowledge and information from other sensors, both onboard and remote. The goal is to create an understanding of the critical components of the environment. Based on this perception, the system is able to reason about subsequent actions. This repetitive process, called the “Cognitive Processing Cycle” [3], is a radar version of human cognitive principles, in the context of human cognition called the “Perception-Action Cycle” (PAC), see figure 2.

Figure 2. “Perception-Action Cycle”.
2.2. Potential operational benefits
Tracking a large number of targets is difficult in terms of time, computational and energy resources. The lack of computational resources is compensated by constantly improving and increasing computational performance, energy due to the improvement of engineering solutions for the construction of receiving and transmitting modules. For temporary resources, the only way is to use them as efficiently as possible within the limits of solving specific problems [4]. Applying a cognitive approach to the MR resource management system can solve the problem of lack of time resources in the following ways.

The target tracking manager [5] schedule the time of issuing the task for updating the target trajectory in such a way as to obtain the required accuracy of its determination. The use of the cognitive approach can reduce the frequency of issuing tasks for updating the trajectory, without reducing the quality and number of tracked targets. This is possible due to a priori knowledge recorded by the radar developer and acquired in self-study during operation.

A priori knowledge includes: a geographical map, a plan of the area, climatic conditions, trajectories and types of targets, the location of interference sources, man-made objects, rules for integrating radar information in the conditions of coordinated interaction of several radars [6]. The acquired knowledge includes: targets wavelet scattering features [7], priorities (degrees of danger) of goals [8], priority directions and sectors of surveillance, estimated parameters of the MR platform movement [9], types and locations of electronic countermeasure and jammers, transmitter parameters.

In addition, knowledge generated during operation includes real-time tracking of the time, energy, and computational resources required for long-term planning of radar missions. Operation in hard real time of all components of the MR control system can determine the severity of his cognitive abilities.

The ability of the cognitive radar to adapt certain performance characteristics can be used to:

- prevention of interception of its signal [10] (detection of radiation and measurement of parameters) by electronic intelligence receivers. These characteristics include the width of the main lobe and the level of the side lobes, the power of the pulsed transmitted signal, the width of the spectrum of the emitted signal, the number of transmitted pulses.
- increasing anti-jamming and counteracting electronic warfare by means of inter-pulse tuning of the carrier frequency of the probing signal.

2.3. Using self-organizing maps for analysis of radar data
Target classification in non-cognitive radar systems is based on the extraction of predetermined target attributes from the received radar signal. Target characteristics are determined by a radar signal processing expert, often after lengthy and complex analysis of a large amount of radar data.

The difficult working regime of the expert reduces the quality of decision making and is a serious problem. Instead of this “manual approach” to the development of characteristics, cognitive radar uses deep learning methods [11]. By automatically extracting relevant characteristics from a set of radar measurements in its long-term memory obtained during previous missions. In particular, it is proposed to use self-organizing maps (SOM), which proved efficiency [12, 13]. The use of unsupervised learning methods transforms the cognitive radar to a new, metacognitive level, and continues the development of the ideas proposed in [14,15].

This automated metacognitive radar feature extraction process reduces the time it takes to adapt the radar to a new mission, as opposed to the traditional expert loop process. Provides additional information for the expert to make strategic decisions. For example, SOM can be used to cluster targets and visualize environmental parameters. The use of SOM for collecting mission statistics is beneficial due to its stability to corrupted and missing sample data.

3. Conclusion
The main directions of the development of cognitive radar:
• Increasing the level of adaptability and learning, increasing planning time when performing all processes in hard real time.
• Transfer of the operator cognitive functions to the automated processes of the radar system.
• The search for new ways to apply artificial intelligence methods to improve the quality of decision-making, taking into account object management in a rapidly changing environment.

Such a solution may be the application of the “principle of purposeful behavior” of cognitive systems, which allows to reduce the share of uncertainty in decision-making situations in situations of rapidly changing countermeasures environment.

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