Towards cognitive artificial intelligence device: an intelligent processor based on human thinking emulation

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ABSTRACT

The intervention of computer technology began the era of a more intelligent and independent instrumentation system based on intelligent methods such as artificial neural networks, fuzzy logic, and genetic algorithm. On the other hand, processor with artificial cognitive ability has also been discovered in 2016. The architecture of the processor was designed based on knowledge growing system (KGS) algorithm, a new concept in artificial intelligence (AI) which is focused on the emulation of the process of the growing of knowledge in human brain after getting new information from human sensory organs. KGS is considered as the main method of a new perspective in AI called as cognitive artificial intelligence (CAI). The design is to obtain the architecture of the data path of the processor. We found that the complexity of the processor circuit is determined by the number of combinations of sensors and hypotheses as the main inputs to the processor. This paper addresses the development of an intelligence processor based on cognitive AI in order to realize an Intelligence Instrumentation System. The processor is implemented in field programmable gate array (FPGA) and able to perform human thinking emulation by using KGS algorithm.

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1. INTRODUCTION

The demands of intelligent instrumentation system are increasing. One of the system's capability is autonomous calibration, where sensors independently carry out calibration due to the measurement results of drifts that are affected by the environment [1]. Changes in analog systems to digital ones increasingly improve the precision of instrumentation systems. The development of artificial intelligence (AI) adds the complexity of instrumentation systems but presents smarter ones and opens wide opportunities for more specialized use and autonomous instrumentation [2]. The development of CAI was triggered by the discovery of cognitive characteristic shows by the brain when generating new knowledge. We call this mechanism as knowledge growing (KG) where the knowledge is obtained after the brain extracted new inferencing from the fusion of information delivered from sensory organs after carrying out interaction to the world. Therefore, we call a system that has ability to grow its own knowledge as knowledge growing system (KGS) along with its computational mehod.

The development of KGS as the main engine of CAI opens the opportunity to create an intelligent instrumentation system where its intelligence is shown with the cognitive ability put in it. This kind of intelligent instrumentation system can be realized by embedding a processor that has cognitive properties, as the main controller of the system. By implementing it, we are sure that a processor which has cognitive ability namely, emulating the way of human thinks can be realized. The cognitive-based processor then will be used to support the development intelligent instrumentation system in various fields [3–8]. Emulating the way of human thinks into a software computer was already a big challenge, and it was even a bigger challenge to implement it into a hardware [9–11]. Other researchers have also mentioned that the cognitive processor system design is expected to contribute to the development of artificial intelligence-based processor designs [12, 13]. In this paper we delivered the technique to implement KGS computation method to create a human thinking emulation processor called as CAI processor or simply cognitive processor, an intelligent device for intelligent system.

2. RESEARCH METHOD

Current conventional computing methods based on AI mostly obtain knowledge based on past data or experiences and not yet equipped with the ability to generate knowledge from brand new data obtained from directly interacting with the world, in this case a phenomenon being observed. In addition, the knowledge generated by the existing AI methods are still limited by using existing data to produce specific goals (supervised learning) or by providing a set of data to see the form of its output (unsupervised learning) [14, 15]. This means that the current AI computational methods are currently not equipped with a feature which gives them an ability to learn something new from the information obtained from their sensory organs that perform interactions to a phenomenon. KGS computation is inspired by the way of the human brain draws conclusions based on information received from the environment [16, 17]. The basic concept of KGS is to emulate the way of human's brain develops new knowledge from the information delivered by human sensory organs gathered from the phenomenon the human interacts with as illustrated in Figure 1 [18]. The process to gain new knowledge is started by sensing the phenomenon and receiving the information regarding it from all sensory organs. This can only be done by making interactions with the observed phenomenon using one or more sensory organs. Mostly, information from only one sensors can only give a little knowledge regarding the phenomenon. By getting more information from various sensory organs, then human can have more knowledge and be able to explain what the phenomenon being interacted with.

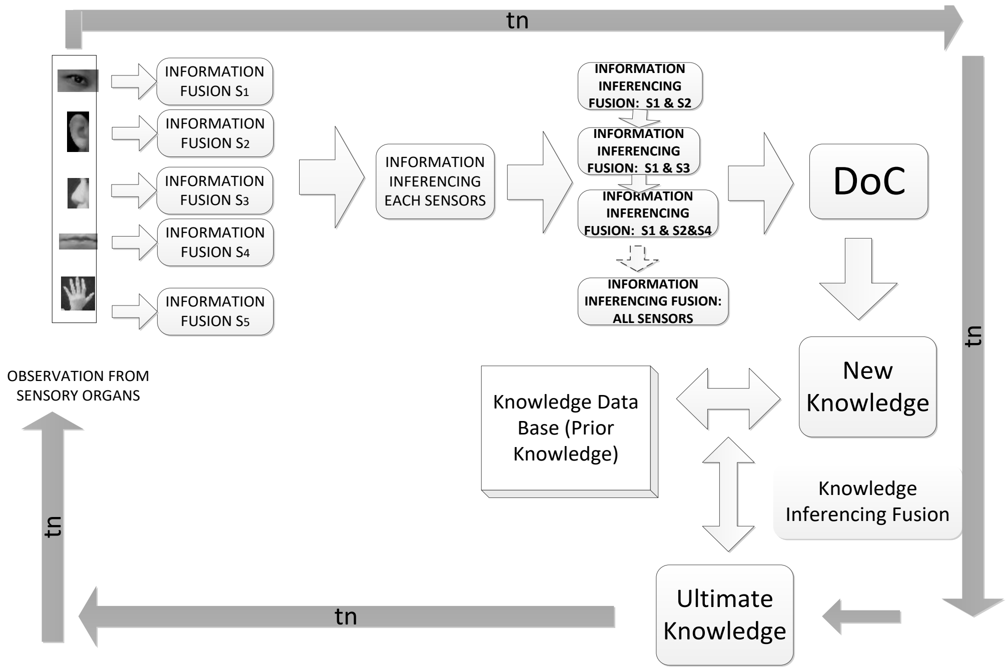

Figure 1. KGS mechanism in growing knowledge

The information delivered from the sensory organs is fused to obtain comprehensive information. Each fused information will its own probability value or DoC which represents the knowledge obtained by KGS about the phenomenon. Each comprehensive information's probability value then becomes new knowledge which is measured with DoC. DoC represents the value of certainty for each new knowledge depending on the sensory organs' information that has been fused. DoC also shows the best combination of sensor data and hypotheses that may occur related to the observed phenomenon. The process of KGS is described by two formulas namely ASSA2010 (Arwin Sumari-Suwandi Ahmad 2010) method for single observation time, and OM-ASSA2010 (observation multi time Arwin Sumari-Suwandi Ahmad 2010) for multiple observation time as shown in (1). The results are in the form of new knowledge probability distribution (NKPD) namely, the list of knowledge of the system regarding the observed phenomenon based on the observed data from the sensory organs[19]. NKPD is knowledge obtained from single observation time while NKPD over time (NKPDT) is the ultimate knowledge of the system after performing a computation to information from multiple times of observation.

$$P(\theta_t) = \frac{\sum_{t=1}^{\tau} P(\psi_t^i)}{\tau} \tag{1}$$

where:
τ = the number of times in multiple observation, τ is replaced with n for single observation time;
$P(\psi_t^i)$ = the best value of the combination of sensor-data and hypothesis at each observation time;
$P(\theta_t)$ = the best combination of sensor-data and hypothesis value at whole observation time.

The ultimate knowledge which the best combination of sensor-data and hypothesis that is obtained from several observation times will also be calculated using DoC with the mathematics formula in (2).

$$\begin{aligned} DoC &= P(\theta) estimate \\ &= \max[P(\theta)_j] \end{aligned} \tag{2}$$

where $P(\theta)_{estimate}$ is the value of DoC which is commonly the greatest value of the combination of sensor-data and hypotheses resulted from the OM-ASSA2010 formula computation. This mechanism will be implemented in hardware which is, in this case, is field programmable gate array (FPGA).

Before implemented in FPGA and based on the preliminary designs of the data path, the VHDL design for CAI or simply cognitive processor was successfully made [20]. Figure 2 shows the flowchart of the KGS algorithm as the basis for designing the data path for the cognitive processor. The process is started with the retrieval of data from sensors which is called an indication, namely information regarding the observed phenomenon. The number of hypotheses is also set up according to the number of sensors used by the system. The number of hypotheses is computed by using (3), where λ is the maximum number of possible hypotheses and δ is the number of the sensor.

$$\lambda = \left(2^{\delta} - \delta\right) - 1 \tag{3}$$

The system will check whether each sensor can observe every condition of the existing hypothesis and put a binary value 0 or 1 depending on the result of the sensor's observation. If all sensor data is already completely received and each value of the combination of sensor data and hypotheses is already filled in, then the next process is the carry out the information fusion and obtain comprehensive information for each combination of sensor-data dan hypothesis. The comprehensive information becomes the inferencing of each combination of sensor-data and hypothesis which will have a variety of probability values depending on the values of all sensor-data and hypotheses for each hypothesis. The inferencing will become a new knowledge of the system. This mechanism is carried out by using (1) and the amount of knowledge obtained at this point is measured with DoC using (2).

This mechanism will continue time by time as long as the system is still making the interaction with the phenomenon, sensing to obtain information, and perceiving it. There is a confirmation whether all inferencing has already been done from t1 to tτ. DoC of each observation time is stored to be fused with the next inferencing if the DoC at this point cannot recognize the observed phenomenon. The components of a cognitive processor that are designed are based on OM-ASSA2010 formula which becomes the algorithm of

KGS. To implement this equation into hardware, we had to form a series of systolic arrays [21–23], with the matrix equation as shown in (4), and it becomes the basis for forming a dependence graph to determine the cognitive processor component as shown in Figure 3. From this dependence graph, the cognitive processor elements are depicted in Figure 4.

$$\begin{pmatrix} P\theta_1 \\ P\theta_2 \\ \cdots \\ P\theta_j \end{pmatrix} = \begin{pmatrix} v_{11} & v_{12} & v_{13} & \ldots v_{1i} \\ v_{21} & v_{22} & v_{23} & \ldots, v_{2i} \\ .. & .. & .. & .. \; .. \\ v_{j1} & v_{j2} & v_{j3} & .. \; v_{ji} \end{pmatrix} \begin{pmatrix} w_1 \\ w_2 \\ \cdots \\ w_i \end{pmatrix} + \begin{pmatrix} \frac{P(\omega)_{t-1}}{t_1} \\ \frac{P(\omega)_{t-1}}{t_2} \\ \cdots \\ \frac{P(\omega)_{t-1}}{t_n} \end{pmatrix} \quad (4)$$

where w1 = w2 =… = wi = w

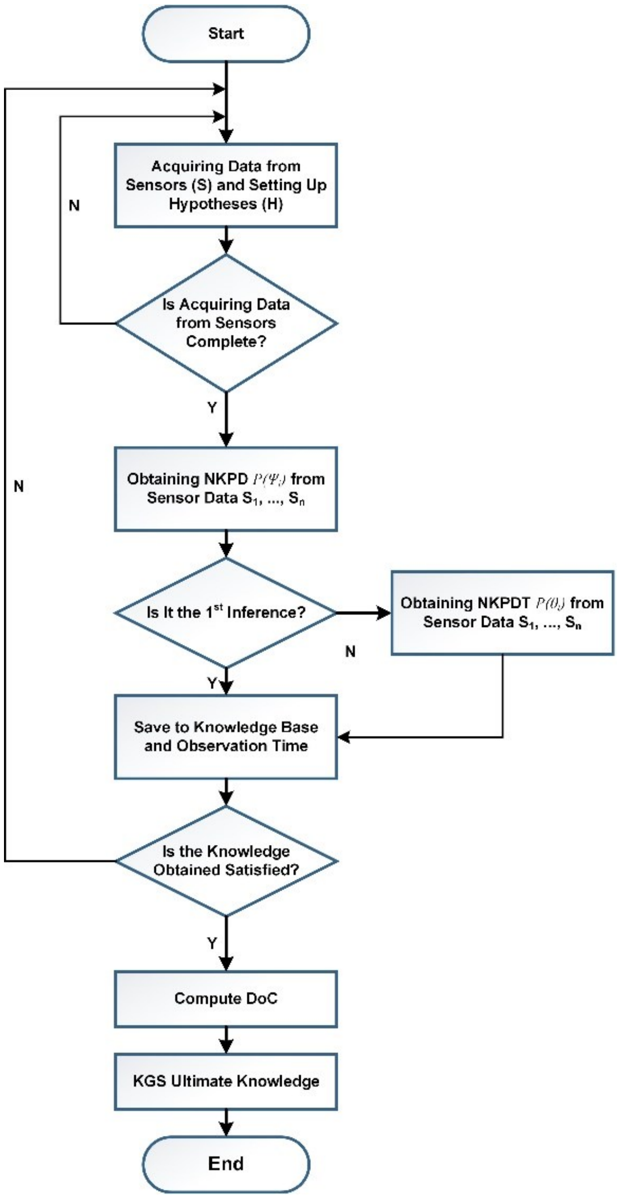

Figure 2. The flowchart of the KGS algorithm as the basis for the design of cognitive processor data-path

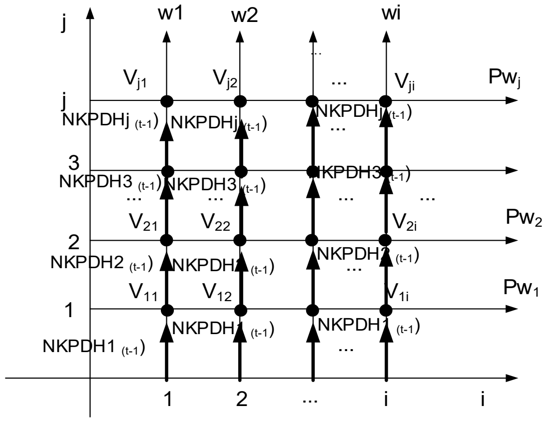

Figure 3. Dependence graph for cognitive processor

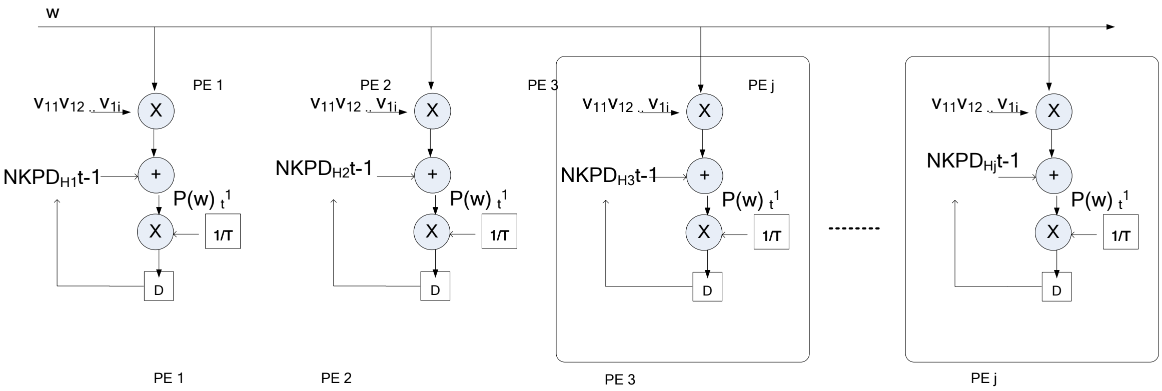

Figure 4. The elements of the cognitive processor

In Figure 4, it can be seen that the OM-ASSA2010 computational circuits consist of multiplication and adder components. The D-Latch register is used to store the calculation results from the adder and multiplication components. In this processor architecture design, the number of adder components is influenced by the number of hypotheses. The number of sensors affects computing time. As an example, a cognitive processor with 4 sensors with 13 possible hypotheses, but we allocated only 8 hypotheses or possible events, it will take 8 adders with a computational time length of 4 timing stages.

3. RESULTS AND ANALYSIS

The testbench simulation for CAI processor is shown in Figure 5, where the system successfully produced DoC values at the 4th computation time. Based on the results of the modeling and the designing cognitive processor, its circuit is implemented in FPGA module [24, 25]. We used Cyclone IVE EPCE6F17C6 which has a total I/O of 180, to implement the designed processor where in this experiment we used 4 hypotheses or probable answers. The results of FPGA implementation for cognitive processor is shown in Figure 6, and the synthesis results of the simulation are given in Figure 7. From the synthesis results, it can be seen that cognitive processor with 4 hypotheses requires 527 logic elements, and 86 pins consisting of 3 pins for the timing element (clock, reset, and enable), 4x4 pin for input register, 7 pins for display counter, and 17x4 pin for output register. The implementation of the cognitive processor in FPGA has also been carried out for a combination of 4 sensor inputs and 8 hypotheses. The implementation results for this configuration show that the required logic elements are 2.162, and 170 pins consist of 2 pins for the timing (clock and reset) elements, 4x8 pin for input register, and 17x8 pin for output register. From the implementation results, it can be seen that the number of hypotheses affects the circuit complexity of the cognitive processor. The more possible events that are set up then the wider the data path should be set up and the higher the number of logic elements will be used. From the experiment results, double the number of hypotheses fourfolds the number of logic elements, from 527 for 4 hypotheses to 2.162 for 8 hypotheses or there is a 310% increase. On the other hand, the number of pins increases from 86 pins to 170 pins or there is a 98% increase.

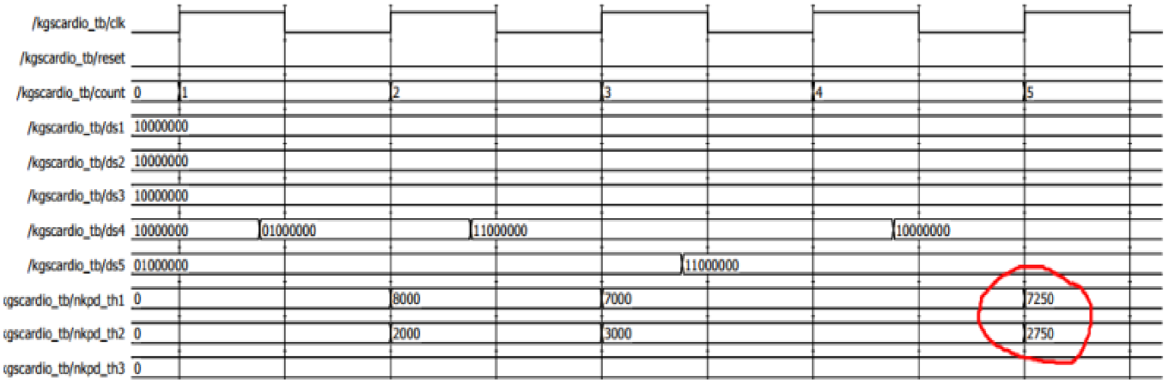

Figure 5. Testbench simulation for the cognitive processor

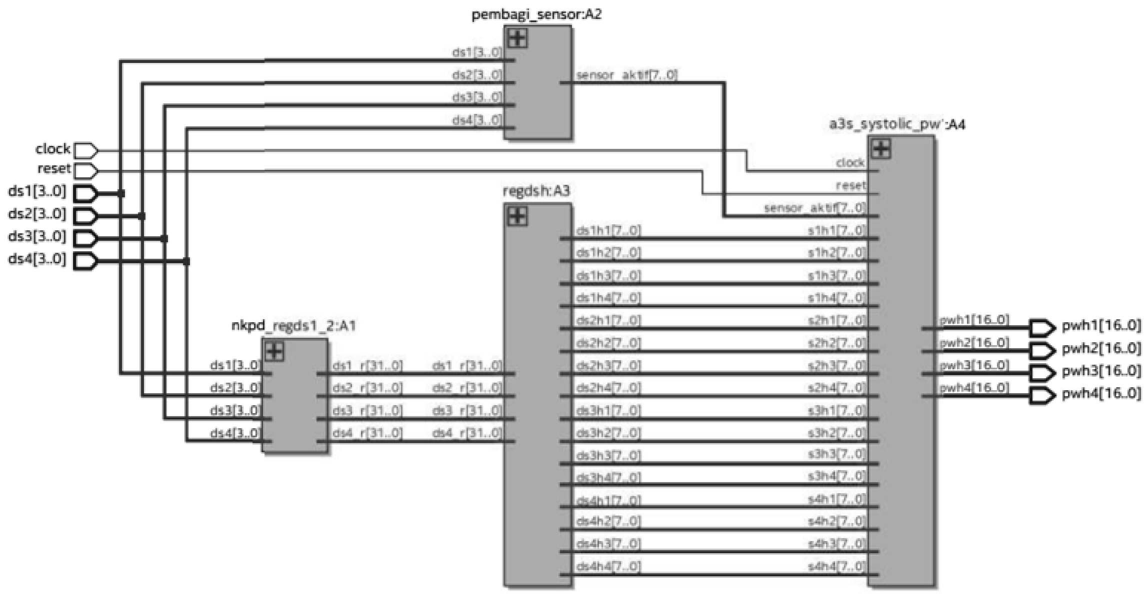

Figure 6. The hardware implementation of the cognitive processor with 4 hypotheses

Flow Status	In progress - Fri Aug 31 02:13:04 2018
Quartus Prime Version	16.1.0 Build 196 10/24/2016 SJ Lite Edition
Revision Name	a3s_systolic_all
Top-level Entity Name	a3s_systolic_all
Family	Cyclone IV E
Device	EP4CE6F17C6
Timing Models	Final
Total logic elements	527
Total combinational functions	527
Dedicated logic registers	4
Total registers	4
Total pins	86
Total virtual pins	0
Total memory bits	0
Embedded Multiplier 9-bit elements	15
Total PLLs	0

Figure 7. The synthesis results of CAI processor

4. CONCLUSION

From our experiments, it can be seen that we have successfully implemented the KGS algorithm into FPGA and also carried out a simulation to show that it works well. Synthesizing its hardware implementation, we found that the complexity of the cognitive processor increases as the number of hypotheses increases which are affected the number of sensors. As can be seen from (3) that the number of sensors automatically affects the maximum number of hypotheses or possible events that can be formed from the computation. It is an analogy to humans, the more sensory organs use to observe a phenomenon then the more probable answers that can be obtained and more knowledge that can be acquired to challenge is how to reduce the number of logic elements increase as the number of hypotheses increase. One of the ways is to find a method to determine the number of the most probable hypotheses for a number of sensors for observing a phenomenon.

From the perspective of hardware implementation, we continue our research in designing a much better cognitive processor based on the KGS algorithm. We believe that our cognitive processor if it is ready in the form of system on chip (SoC), it would be the main supporter for the autonomous mobile electronic instrumentation system. The implementation of a CAI-based processor can improve the performance of the intelligence instrumentation system because of its ability to increase its own knowledge as time passes based on the inputs it receives from the phenomenon in its surroundings, as it is done naturally by humans in their daily life.

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Catherine Olivia Sereati got Bachelor degree of electrical engineering (EE) from Brawijaya University Malang, then pursued Master of Technology and Doctor in Electrical Engineering, both from Institut Teknologi Bandung (ITB). Now Catherine is a lecturer and researcher at Universitas Katolik Indonesia Atma Jaya. Her interest subject of researches are electronic instrumentation system and system on chip (SoC). She was also involved in several research projects to design cognitive instrumentation systems. Some of them are a building a software cognitive interpretation of ship movements, for Indonesian marine security purposes, and cognitive electro cardiograph (ECG) design. Currently her research project is focusing to designing the architecture of cognitive processor.

Colonel Arwin Datumaya Wahyudi Sumari is 1991 Indonesian Air Force Academy graduate. He received Sarjana Teknik (S.T.) in Electronics Engineering (1996), Magister Teknik (M.T.) in Computer Engineering (2008), and Doktor (Dr.) in Electrical Engineering and Informatics (2010) from Institut Teknologi Bandung, Indonesia. In 2009, he along with Prof. Dr.ing. Adang Suwandi Ahmad invented knowledge growing system which is the foundation of Cognitive Artificial Intelligence. Currently, Arwin is Senior Electrical Engineer Officer at Abdulrachman Saleh AFB, Malang. He is also Assistant Professor at Faculty of Defense Technology, Indonesia Defense University and Adjunct Professor at Department of Electrical Engineering, State Polytechnic of Malang. He has been developing and enhancing cognitive artificial intelligence for various field especially for Defense and Security.

Adang Suwandi Ahmad received his engineering degree in Electrical Engineering from ITB, Diplome Etude Approfondi Signaux et Bruits (DEA) option Electronique, and Docteur Ingenieur Signaux et Bruits option Electronique (Dr.- ing) from Universite des Sciences du Languedoc Montpellier, France became Institut Teknologi Bandung's Professor in Intelligent Electronics Instrumentation System in 2000. Adang's past researches were in Electronics Instrumentation systems and intelligent electronics systems/artificial intelligence. He has also expanded his research in bioinformatics computation, information sciences, intelligent computations, and intelligent-based instrumentation systems. In 2009 - 2018 Adang Suwandi Ahmad has developed Cognitive Artificial Intelligence as a new method of artificial intelligence.