Architecture Design For Multi-sensors Information Fusion Processor

Catherine Olivia Sereati, Arwin Datumaya Wahyudi Sumari, Trio Adiono , Adang Suwandi Ahmad
School of Electrical Engineering and Informatics, Institut Teknologi Bandung, Jl. Ganeca 10 Bandung – 40132, INDONESIA

Email : catherine.olivia@atmajaya.ac.id

Abstract— This paper discusses the architecture design for information fusion processor. This processor will emulate the human way of thinking by drawing conclusions from the collection of information obtained. By using VHDL, architecture design for this processor is based on Knowledge Growing System (KGS) algorithm. KGS is a novelty in AI methods that focuses on observing the way humans grow their knowledge based on the information it receives. By using KGS's algorithm, this processor work by receiving input from set of sensors and hypothesis. This processor generates value which is called Degree of Certainty (DoC), which show the most possibilities hypothesis among all alternative hypothesis The results show that a data path which have been design for this processor is able to perform KGS computation process. Because the ability to perform information fusion from multi-sensors, this processor will support the enhancement of hardware which support the operation of Big Data system.

Keywords— processor design, Information Fusion, VHDL, VLSI

1. Introduction

In the Big Data era, Information and data come from a variety of sources. Different types and variety amounts of data, is processed to gain a set of information about the situation which is being observed. Wireless sensor network, body sensor network, even the autonomous vehicle are several example of hardware technology development that supports the big data applications. Therefore the existence of hardware which have ability for doing computation to process s information from a set of data is needed. Not only received a set of information from different kind of sensor, but also fuse the information, take the inference from information which have received, and take into action according the conclusion which have been made. This phenomena emerge the idea to design a processor that can receive input from a complex sensor circuit. Not only accept, but also process the input of each sensor, combine the results with other sensors and take the conclusion according of the condition which being observed. The conclusion then becomes a reference for the occurrence of an action. For example on a smart home system, the processor will receive input from an integrated sensor to control the environmental conditions and the security of the house. In an autonomous vehicle, the system will receive input from a collection of sensors becomes a reference for the movement of the vehicle.

KGS is a novelty in Artificial Intelligence that emulates knowledge growth inside of human brain by collecting information from observed conditions, do information fusion, and forming new knowledge of observed phenomena. The KGS method has been used in designing Probabilistic cognitive robot [1]. In the field of instrumentation, KGS is being developed to assist the decision-making process for monitoring the condition of the transformer [2]. In the field of hardware security KGS has also been developed as a system for side channel attack counter-measure [3].

Several studies related to Very-Large Scale Integration (VLSI) and SoC technology ever developed a processor design by implementing some artificial intelligence method into its processor architecture [4] [5] [6]. The use of KGS algorithm in a processor design can be a new development for processor design because of its ability to extract information from a collection of sensors and generate knowledge. The result of the knowledge is used to determine the (decision making) action that must be done by the device connected with the processor.

This paper delivers the methodology to design architecture of multi-sensors information fusion processor. How to translate KGS algorithm in form of VHDL language and the results obtained, are discussed in this paper. This paper will be closed with an explanation of the next stage of the research plan to improve the Cognitive processor system.

2. Information Fusion for Knowledge Growing System

In 2009, Arwin Datumaya Sumari, Adang Suwandi Ahmad, Aciek Ida, and Jaka Sembiring, have developed a new concept in area of Artificial Intelligence (AI) called Knowledge Growing System (KGS) [7]. The key of KGS concept is to emulate the way of human's brain gain new knowledge from the information delivered by its sensory organs gathered from the environment. Figure 1 shown the KGS mechanism. First, by receiving information and phenomenon from sensory organs, process to gain new knowledge is started. Then, every information delivered from sensory organ is fused to obtain comprehensive information. This process will produce a new knowledge and have a value which is called Degree of Certainty (DoC). DoC represent the value of certainty for every new knowledge. Process to gain DoC value is shown in Figure 2.

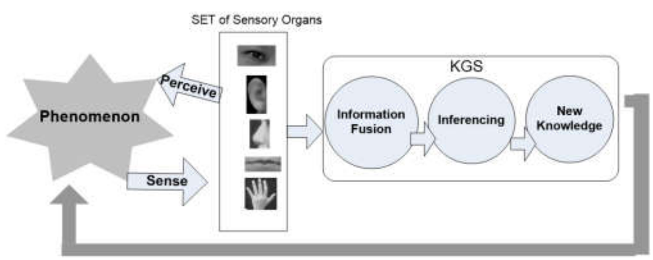

Figure 1. KGS Mechanism [7] [8]

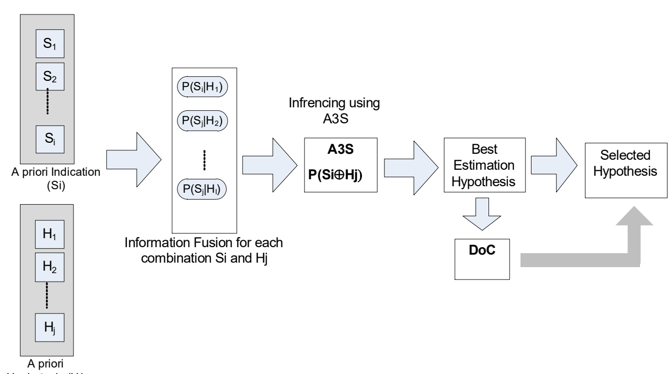

Figure 2. Mechanism to gain DoC value, started by fuse information from sensors and hyphotesis [9]

KGS Mechanism is represented by A3S (Arwin Adang Aciek Sembiring) formula as described as follow :

$$P(S_i \boxplus H_j) = \max_{j=1,\ldots,m} \frac{\sum_{i=1}^{n} (P(H_j \mid S_i))}{n} \qquad (1)$$

Where :

P(Hj|Si)	: posterior probability, the probability of hypothesis B when A is occured
P(Si $\boxplus$ Hj)	: Result of Information fusion, the best hyphotesis for every indication.
i	: 1,2,..,n = number of indication
j	: 1,2,3,... m = number of hyphothesis

The results of this A3S equation represent the best hypothesis from one observation time, which will also be referred to as New Knowledge Probability Distribution (NKPD). Furthermore the NKPD value will be accumulated to get the DoC value for an observation.

3. Design Methodology and Result

3. 1. Information Fusion Computation

To further deepen the understanding of the KGS computational flow, a set combination of sensors and hypotheses is made in form a table, as shown at Table 1. Assuming there is 4 hyphothesis and 4 sensors. According to DoC computation mechanism and A3S equation, steps of KGS computation can be explained as :

1. Counting NKPD for each sensors :

Table 1 is illustrated the example observation of a system which have four sensors (S_1 .. Si, i = 4) four hypotheses (H1 ... Hj, j = 4) (see Figure 2). The observation result is represented by logic '1' which indicates that the corresponding hypothesis is in accordance with the sensor observation, whereas logic '0' states otherwise.

Tabel 1. Illustration of Observation Result.

Sensors	Hypotesis			
	H_1	H_2	H_3	H_4
S_1	**0**	**0**	**0**	**1**
S_2	**1**	**0**	**1**	**0**
S_3	**1**	**0**	**0**	**1**
S_4	**1**	**1**	**0**	**1**

By using the A3S algorithm, result of determining NKPD value can be shown in Table 2 below.

Tabel 2. Result of NKPD Value for sensor-hypothesis relationship base on A3S Equation

Sensors	Hypotesis			
	H_1	H_2	H_3	H_4
S_1	**0**	**0**	**0**	**1**
S_2	**0,5**	**0**	**0,5**	**0**
S_3	**0.5**	**0**	**0,5**	**0**
S_4	**0,33**	**0,33**	**0**	**0,33**

Table 2 shows that the results of NKPD calculation generate integer number. The number corresponding to the A3S equation is the result of the division of the number of bits '1' in each combination of sensors and hypotheses. Therefore it is necessary to prepare a register that can accommodate the number. Table 3 shows the conversion of NKPD values from an integer to a binary number.

Tabel 3. Conversion Result of NKPD Value from Integer to Binary

Sensors	Hypotesis			
	H_1	H_2	H_3	H_4
S_1	00000000	00000000	00000000	01100100
S_2	00110010	00000000	00110010	00000000
S_3	00110010	00000000	00110010	00000000
S_4	00100001	00100001	00000000	00100001

2. Counting NKPD for overall Sensors-Hyphothesis (SiHj)

After the NKPD value of each sensor is found, then the next step is to calculate the NKPD of the whole sensor and hypothesis (NKPD SiHj). Illustrative calculations at this stage can be seen in Table 4.

Tabel 4. Result of calculating overall NKPD Value

Sensors	Hypotesis			
	H_1	H_2	H_3	H_4
S_1	0	0	0	1
S_2	0,5	0	0,5	0
S_3	0,5	0	0	0,5
S_4	0,33	0,33	0	0,33
NKPD	0,332	0,0825	0,125	0,457

The NKPD results in this observation (t1) of the entire SiHj, according to the A3S equation, are derived from the sum of the NKPD H1 values (ie S1H1 + S2H1 + ...), the NKPD H2 value (ie S1H2 + S2H2 + ...) and so on ,divided by the number of active sensors. If any sensor generates a value of '0000' then the sensor does not get information from the existing hypothesis and is not included in the calculation.

- (H1) 0.457 (represented by 4575, which means 45.75%)
- (H2) 0.125 (represented by 1250, which means 12.50%)
- (H3) 0.0825 (represented by 825, which means 8.25%) and
- (H4) 0.3325 (represented with 3325, which means 33.25%).

It can be seen that the value of total NKPD (H1 +H2 +H3 +H4...) = 1, which represented 100%. From the computation result which represented at Table 4, show that NKPD value of H_1 has the biggest value, compare with all NKPD value among all hypotheses (H_1 to H_4). As explained at section above, DoC value represent the best hypothesis of a phenomenon which being observed. So, the DoC value is represented by the NKPD of H_1 of this observation.

3.2. Architecture Design of Multi-sensors Information

To design the architecture of this processor, it is important to understand what components will form the proceses of the system. Components for multi-sensor fusion processor, as shown at Figure 3, are designed based on the existing A3S formula in equation (1). In this paper processor architecture to perform A3S computing is used to receive input for a combination of four sensors and four hypotheses

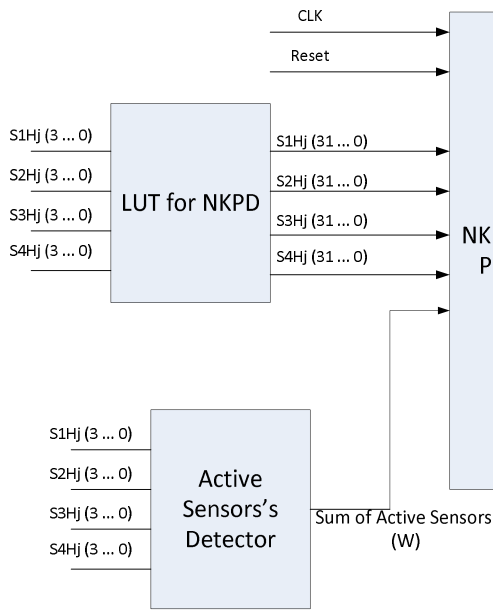

Figure 3. Component of Multi-sensors Information Processor

As explained above, the first step of computation is to count the value of NKPD for every combination sensors and hyphothesis. There is a Look Up Table component which is used to convert the result of NKPD of sensor-hyphothesis relations (as shown at Table 2) into appropriate binary number combination (as shown at Table 3). According to A3S equation, since there is a division operation of each hypothesis with the number of sensors, it is necessary to detect the number of sensors. So this processor also equipped with the "active sensors detection" component.

Systolic Array processor architecture is designed to process the NKPD overall computation, as shown at Table 4. Why systolic array architecture? Because the systolic array design meets the requirements of reconfigurable design. So in the future, if the system will be developed to receive more complex information does not require more component resources. The processor element of systolic array processor to process A3S equation is shown at Figure 4.

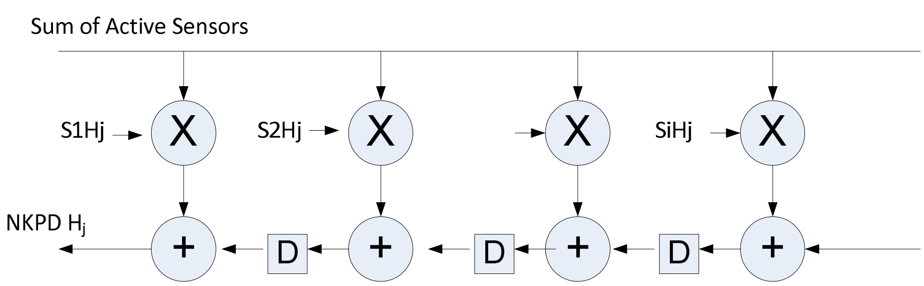

Figure 4. Systolic Array Processor of A3S computation

Before being synthesized using FPGA, this design is simulated using ModelSIm tools to show the performance while computing the A3S equation. Simulation result can be shown at Figure 5.

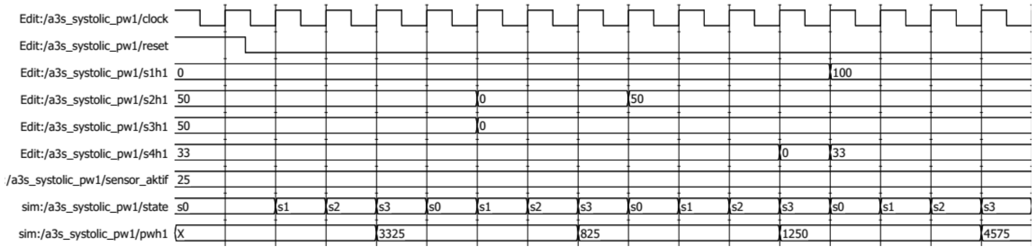

Figure 5. Simulation result of A3S Computation

From the simulation, can be shown that this design able to perform A3S equation. Computation time to gain NKPD value for each hypothesis is depend to the number of sensors. .

This designed also synthesized using FPGA Quartus II.13.1. Synthesized result is shown at Figure 6.

Analysis & Synthesis Status	Successful - Thu May 31 19:47:07 2018
Quartus Prime Version	16.1.0 Build 196 10/24/2016 SJ Lite Edition
Revision Name	a3s_systolic_pw1
Top-level Entity Name	a3s_systolic_pw1
Family	Cyclone IV GX
Total logic elements	116
Total combinational functions	116
Dedicated logic registers	4
Total registers	4
Total pins	59
Total virtual pins	0
Total memory bits	0
Embedded Multiplier 9-bit elements	4
Total GXB Receiver Channel PCS	0
Total GXB Receiver Channel PMA	0
Total GXB Transmitter Channel PCS	0
Total GXB Transmitter Channel PMA	0
Total PLLs	0

And RTL result is shown at Figure 6.

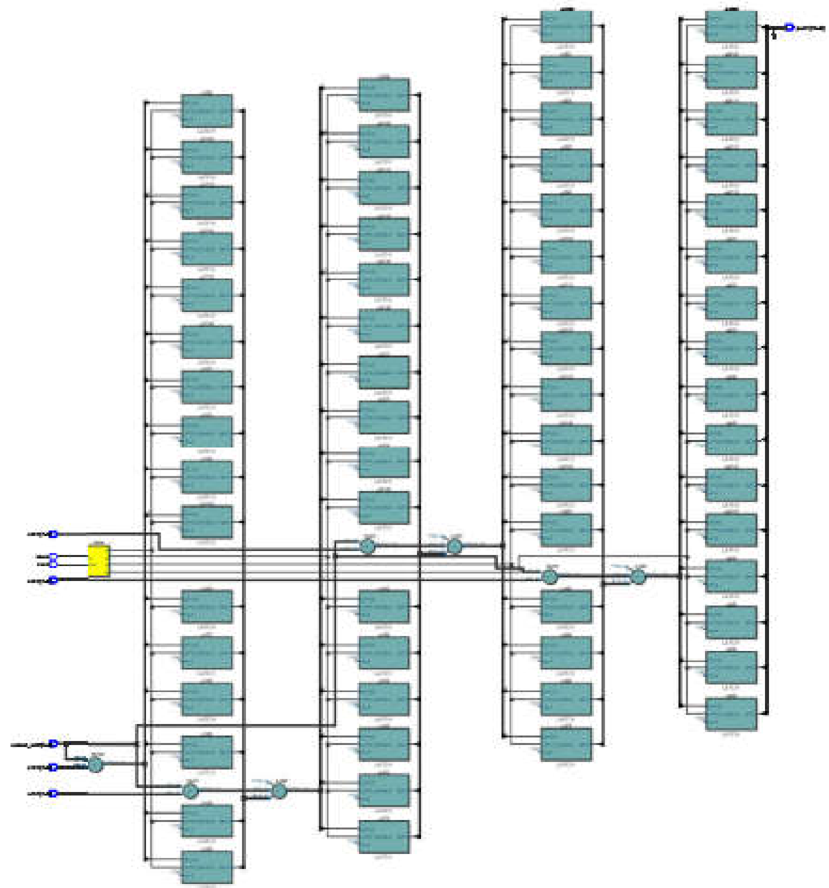

Figure 6. RTL Result of Multi Sensor Information Fusion Processor

Synthesis results of this processor design show that the processor chip has a total of 116 logic elements. This design will generate the DOC value which represent with 32 bits width for each hypothesis.

4. Conclusion and Future Works

This paper deliver the methodology of designing datapath for Multi-sensor information fusion processor, using KGS Algorithm. The result show that the design of processor able to perform A3S computation. Result of this processor design is value of DoC as represented of the value of possibilities from hyphotesis correspondent with available sensors. Design improvements will be made by adding an bus interface so this processor able to communicate with another peripherals

After implementing this KGS algorithm in form of Multi-sensors information fusion processor, we will continue doing research to design Cognitive Proccessor which equipped with algorithm of KGS. With KGS algorithm, cognitive processor can be used as a main control for an autonomous system, which has ability to grow it knowledge continuously, as time passes. This system come in form of System of Chip (SoC), so cognitive processor will have ability to support the development of autonomous-mobile electronic instrumentation.

References

[1] W. Adiprawita, A. S. Ahmad, J. Sembiring, and B. R. Trilaksono, "New resampling algorithm for particle filter localization for mobile robot with 3 ultrasonic sonar sensor," in Proceedings of the 2011 International Conference on Electrical Engineering and Informatics, jul 2011, pp. 1-6.

[2] K. O. Bachri, B. Anggoro, and A. S. Ahmad, "Interpreting DGA Key Gas using Fuzzy OMA3S," in 2016 International Symposium on Electronics and Smart Devices (ISESD), nov 2016, pp. 137-142.

[3] S. D. Putra, A. S. Ahmad, and S. Sutikno, "DPA-countermeasure with knowledge growing system," in 2016 International Symposium on Electronics and Smart Devices (ISESD), nov 2016, pp. 16-20.

[4] Liu Dong, "A study on multiple information fusion technology in obstacle avoidance of robots," in 2010 Second Pacific-Asia Conference on Circuits, Communications and System, vol. 1, aug 2010, pp. 171-174.

[5] V. N. Kumar, H. Bhalavi, G. Lakshminarayanan, and M. Sellathurai, "FPGA based decision making engine for cognitive radio using genetic algorithm," in 2013 IEEE 8th International Conference on Industrial and Information Systems, dec 2013, pp. 633-636.

[6] Gabriele-Maria, Antonino Laudani, Francesco Riganti Fulginei, and Alessandro Lozito Salvini, "FPGA Implementations of Feed Forward Neural Network by using Floating Point Hardware Accelerators," , vol. 12, 2014, pp. 30-39.

[7] A. D. W. Sumari and A. S. Ahmad, "Constructing brain-inspired knowledge-growing system: A review and a design concept," , 2010.

[8] A. D. W. Sumari and A. S. Ahmad, "Cogitive Artificial Intelligence: The fusion of Artificial Intelligence and information fusion," in 2016 International Symposium on Electronics and Smart Devices (ISESD), nov 2016, pp. 1-6.

[9] C. O. Sereati, A. D. W. Sumari, T. Adiono, and A. S. Ahmad, "Implementation Knowledge Growing System Algorithm using VHDL," in 2016 International Symposium on Electronics and Smart Devices (ISESD), nov 2016, pp. 7-10.