A New Abstraction Model for Biologically-Inspired Sound Signal Analyzer

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***Abstract*—This paper studied the human ear and human brain as a new idea to analyze sound. The human ear to be exact; the eardrum detects the sound signal and the cochlea filters the frequency signal. Subsequently, the brain is capable to recognize and learn the sound signal. This research mapped the biologically-inspired ability to computational process then developed an abstraction model. From this model it provided a guideline to obtain the capability requirements for the of sound signal analyzer as a new idea for information retrieval. The research aims to generate faster and more detailed results as well as to achieve better accuracy in producing definite sound. Therefore, this research proposed an abstraction model of human ear and human brain to developed biologically-inspired sound signal analyzer (BISSA).**

***Keywords* — Biologically-Inspired; Information Retrieval; Noise Filtering; Sound signal**

I. INTRODUCTION

The main purpose of this research is to study how human filters the distracting noise and only recognizes to the desired sound that we want to listen. For instance, a recorded song is played; for example the national anthem. We can hear the voice of the lyrics as well as the sound of the music such as the piano and the drums from the playback. The question is what if a person asked another person to imitate the sound of the drums snare from the playback. So, when the person listens once again to the playback, he will try to recognize the drums snare and learn it before he can make the sound. What happens here is the sound wave goes through the ear and hits the eardrum. Eardrum sends the signal to the cochlea and cochlea will filter the resonance. Then the brain recognizes the required sound signal and sends messages to the human to produce the intended sound [1, 2, and 3].

Noise filtering is one of a method to separate the collection of data between the intended and distracted records which are gathered from data abstraction. Filtering noise process usually done for image processing. The image captured often not clear and distorted by noise thus compromise the level detail of data. Besides image processing, audio and spoken processing also filter the data to obtain information, however only for speech recognition which detects specific words or sentences. Another process which detaches the processed data between unintended information is metal detector. The magnetic pole only discovers metal and cannot locate other structure. Hence, this research tries to develop a process that unravels the problem in the entire situation [1, 2, and 3].

BISSA is a new idea for information retrieval. It detects sound signal; not image or visual even magnetic pole to abstract the information. It can be used for many situation especially to collect information of many data that are collected together with divert data which cannot be used or helpful for the process. BISSA takes into account the time and space factor for the process execution by supplying BISSA with memory. The database for BISSA is less complexity; it can recognize and learn the sound signal rather than only keep the information. This behavior matches the process of human brain which can learn and recognize sound signal. Therefore, with this new idea of BISSA, it assists people to assemble information to great benefits.

BISSA brings many benefits for instance the exploration for mineral, such as; petroleum and gold beneath the earth. Each mineral produced different signal frequency to be detected. The research necessity and importance bring a big significant to assist geologist in generating faster and more detailed results. It also can achieve better accuracy in oil and gas well prediction. This research also can be implemented for the medical aspect. For instance, autistic children can use the implementation of this research to a system that can help them to develop language and other communication skills to the usual level. Other than that, the sound signal analyzer also can be implemented in farming and plantation sector. It can detect predator such as snake and rat and use signal frequency to chase them away for safety proposes in the plantation. To wrap up, this research can bring many benefits to many sectors in everyday living life.

As for these reasons stated before, this research studies the problem of how to develop BISSA as a new concept to collect information. The objective of this research is to investigate the biologically-inspired processes from the human ear and the human brain on how to develop BISSA. This solution is realized by the establishment of a new idea for the construction of BISSA. The research necessity and importance bring a big significant in generating faster and more detailed results, as well as better accuracy in producing definite sound. Therefore, with the analysis of the biologically-inspired entities, this research discovers the capability requirements to develop BISSA as a new idea for information gathering.

II. Related Work

To start with, Malcolm Slaney introduced the Cascade-Parallel Model which at each point in the cochlea the acoustic wave travel down the line is filtered by stages of notch filters and resonator furthermore, at each stage getting filtered at lower and lower frequencies [4]. Then followed by Elena Grassi who created a model that split the sound signal into frequency channels by the cochlear filters and then the frequencies are tuned in separate pathways [5]. After that she enhanced the model where the time and level of processing are extracted and processed the position estimates based on each frequency channels individually in parallel pathways and then combined trough a weighted average [6]. Both of the researchers tried adapting the biologically-inspired of human ear to filter the resonances, but the model they created didn't show explicitly the adaptability of the human brain for the recognition and the learning processes for the sound signal.

There is also a model that by compressing and expanding (companding) the signal with a pre-filter; a compression block, a post-filter; an expansion block with the same resonant frequency in every channel by the pre-filter and post-filter banks which have a logarithmically spaced resonant frequencies that span the desired spectral range [7]. Recently by Graham, The Capacitively Coupled Current Conveyor Model or C4 performs the frequency decomposition in a manner more closely matched to the actual cochlea by using an array of bandpass filters in parallel rather than the cochlear models incorporating a cascade of lowpass filters [8]. These studies attempted to solve the different range of sound signal by providing their solution although the researches didn't explain much about the matching of the independent variables with the dependent variables.

For the moment, usually researchers in the past and present days use visual and image to abstract data [9, 10, 11, and 12]. The process to gain the information from the data noise is also collected. This situation mainly happens to the oil and gas company to predict the existence of hydrocarbon beneath the sea bed. Big oil and gas companies such as SHELL and Exxon Mobil invest millions of dollars to develop technology to improve the process of filtering noise from the visual images [13 and 14]. With the uncertain result from the noise filtering process, it brings a lot of problem and loss for the big company so they need support with a new solution.

Furthermore, in the medical aspect, the autistic children are having problems to hear sound up to the normal level. These children cannot listen as well as focus to what people around them are talking, especially to them [15 and 16]. As one of the senses in the human body, hearing of these children can be improved with a new device that can control the frequencies to the level that can possibly charge their attention to receive command or speech from people around them.

Recently, many papers on sound signal had been done by previous researcher, but most of them only focused on the subject of auditory and speech problems. There were many projects tried to improve speech recognition and noise filtering used for spoken and auditory purpose only [17, 18, and 19]. This research tries to bring one step further to use this new idea as a data abstraction method to improve from the visual data abstraction method which is widely used nowadays. Because of that, this research is different from any other speech and spoken research on how to remove noise commencing to sound signal. To wrap up, this paper analyzed the previous work and investigated the biologically-inspired functions of the human ear and the human brain to develop an abstraction model in producing definite sound.

III. Biologically-Inspired Concept

Sound is one of the media that brings information to human. However this information also distracted by noises that surround us. Everyday we listen to much kind of sounds and noises. We can hear the high volume of noise such as a flying jet or an F1 racing car. We also hear the normal volume of sound such as the conversation between two persons. Moreover, we can also hear to the low volume of resonance such as the sound of a clock ticking on the wall. How human brain recognizes to the required sound is very much impressive. Vice versa, the human brain can learn to the new sound. Thus, we can just concentrate to the sound that we want to listen only. For instance, when two human communicate each other, to be precise in a loud area such as at the market, both are paying attention to the conversation of what they are talking only. Here, in this situation, human without notice can filter the unintended noise and only recognize merely to the particular sound we wanted to listen [1, 2, and 3].

The ear is divided into three sections: the external, middle and inner ear. The external ear consists of the pinna (or auricle), the external auditory canal (or ear canal), and the tympanic membrane (or eardrum). The inner ear is separated from the middle ear by another membrane, called the oval window. The middle ear contains three ossicles, or bones; malleus, incus and stapes, which connect both of these membranes and transmit sound to the inner ear [20]. As a consequence, the detection of sound signal is made by the eardrum and the filtration of signal frequency is made by the cochlea.

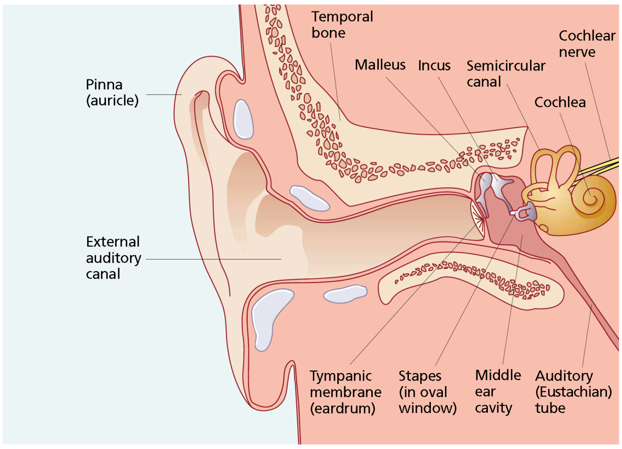

Figure 1. Structure of Human Ear [18].

Within the bone of the cochlea are three fluid-filled chambers that are separated by two membranes. The input to the cochlea is in the scala vestibuli, which is connected at the apical end to the scala tympani. Pressure differences between these two chambers leads to movement in the basilar membrane. The scala media is isolated from the other two chambers. The human cochlea has different tonotopic area in the basilar membrane which exponential changes in the resonance frequency for linear distances down the length of the cochlea [8]. Accordingly, the sound signals are accumulated into signal noise and sorted in the cochlea for the brain to proceed with the next step of recognizing and learning the sound signals.

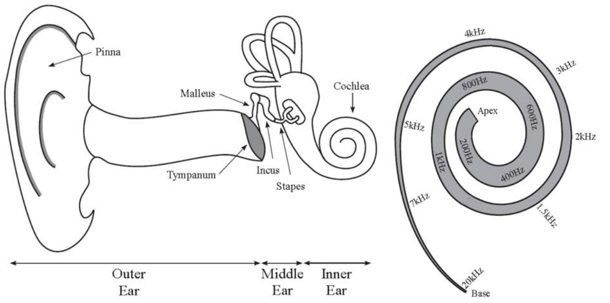

Figure 2. The Tonotopic Area in the Cochlea [5].

The human brain is interconnections of 100 billions of nerve cells that communicate with many others to overwhelm the neural circuit of the complex organization in brain. Each brain cell structure can receive input and process the output within the neuron cell. The auditory system in the brain concurrently interprets many sound criteria such as loudness, pitch, harmonics, and the timing of numerous sounds and from the resource [21]. At this point, recognition and learning of the sound signal are made in the brain and the information can be observed out of the data collected.

A mapping of the biologically-inspired entities to a computational process helps to discover the functions to create a sound signal analyzer. It summaries the essential functions to built BISSA. It also depicts the high level vision of the system model. From the understanding of the analysis made of the biologically-inspired concept, a mapping table is made.

TABLE I. MAPPING TABLE.

Entities	Function	Description
Eardrum	Detect	Load the sound file into the system.
Cochlea	Filter	System arranges the detected sound signal into different signal frequency ranges and updates it into the noise table.
Brain	Recognize	System matches the sound signal from the noise table with the match table and updates the learned sound signal into recognize table, then retrieve the definite sound.
	Learn	System identifies the non-match sound signal from noise table with the match table and updates the learned sound signal into learn table.

IV. BIOLOGICALLY-INSPIRED SOUND SIGNAL ANALYZER (BISSA)

Besides the detection and filtration process, BISSA emphasis on the recognizing and learning of the sound signal. These criteria try to solve problem of how to generate faster and more detailed results as well as to achieve better accuracy in the information retrieval. The best way to show the conceptual model for BISSA is by the creation of block diagram showing the flow of the mentioned process.

A. Previous Work

From [1, 2, and 3], the detection process loaded the sound file into the system. Sound file contained the sound signal is divided into small packages. This process is called token. For each token, the sound signal is detected and given a generated key. In that case, these signal frequencies are recognized and learn sequentially. All the processes are updated steps by steps in the memory where the matching process is done with the dependent variables which are stored primarily in the system. Here, all the processes of detection, filtration, recognition, and learning are clearly showed based on the analysis made in the mapped table. The conceptual model created before really helps this research to further discover the true processes for BISSA. This research continues with the processes of detecting, filtering, recognizing and learning the sound signal. The latest design of the conceptual model shows the predefined process together with the detail process as well as the database view of the tables for BISSA.

B. BISSA Conceptual Model

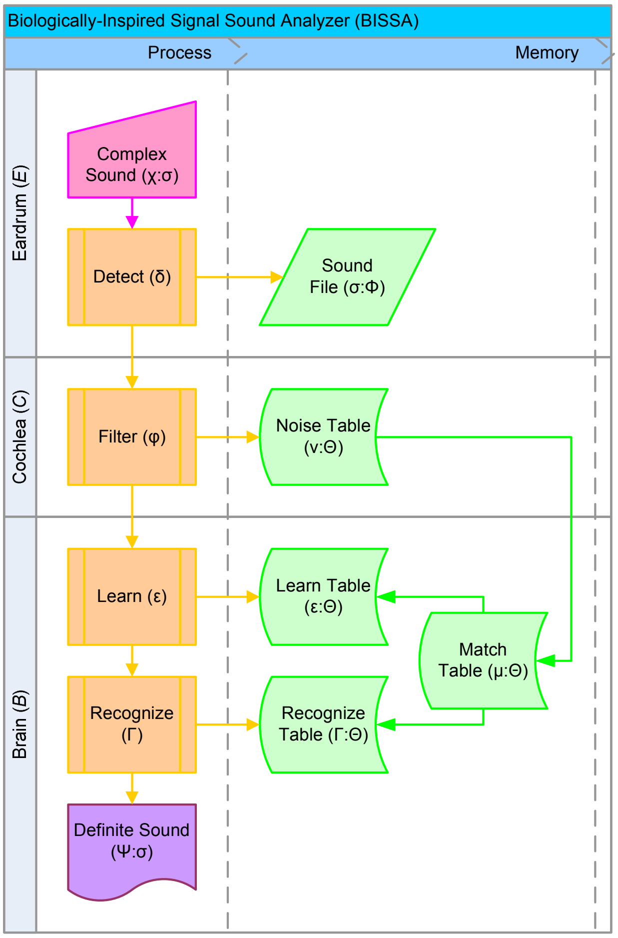

Figure 3. Block Diagram.

The conceptual framework elaborates the capability requirements to build the sound signal analyzer. It shows the flow of processes for BISSA. BISSA is a developed system that capable to receive complex sound and then convert the complex sound into a sound file. Here, it means that BISSA records the real time sound and temporarily store it in the database. The sound file then will be sorted into signal frequency ranges which are detected and it will be saved in a noise table. The records in the noise table then will be matched with the records in BISSA which are predetermined in the match table (for explanation about tables, see next section). The records which are the intersected from the noise table and the match table is the recognize sound. These records are stored in the recognized table, and then will be retrieved as the definite sound. The definite sound is the main result or output for BISSA. Meanwhile, the records which are the intersected records between the complement records of the match table and the noise are save as learned sound in the learn table. The block diagram depicts the high level processes and memory views for BISSA for better understandings.

BISSA needs details processes to make it work; the characteristic of activation for the sound signal analyzer is the system starts when an operator load/capture/insert the sound file into the sound signal analyzer process. For the pre-condition of the sound signal analyzer, the memory or database of the system should be initiated with matching data. Here, the system has the match table for the sound signal analyzer process to do recognize function by comparing the records which is obtained from the sound file with the records in the match table inside the system. There will also be a GUI for inserting the sound file and for displaying the definite sound result.

However the block diagram does not show the responsibility and the interaction for each component of BISSA. This research needs the attributes and methods for each components of BISSA. The object oriented analysis and design can visualize these attributes and methods. Therefore, this research creates an object oriented class diagram to demonstrate the static structure of BISSA by showing the system's classes, their attributes, and the relationships between the classes.

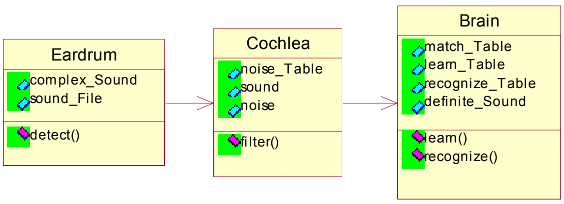

Figure 4. Class Diagram.

V. THE ABSTRACTION MODEL

BISSA system model depicts the logic of the functions. Let E = eardrum, where E is capable to detect sound signal. Here, E = detect, where detect = δ. Hence, E = δ. Let C = cochlea, where C is capable to filter different signal frequencies. At this point, C = filter, where filter = φ. Thus, C = φ. Let B = brain, where B is capable to recognize and learn the signal frequencies as well as GET definite sound. Now, B = recognize + learn, where recognize = Γ, and learn = ε. So, B = Γ + ε. Nevertheless, the functions of each component are described in the separate components.

BISSA needs a set of standard instructions to depict the processes of detection, filtration, recognition and learning. The step by step instructions brings the procedure for solving problem, especially to the processes mentioned before. This research provides a set of formally specified instructions based on the detail analysis for BISSA. The formal step by step instructions are:

- Start the Eardrum (E) component.
- Do Detect (δ) function.
- Insert complex sound (χ:σ) into the system.
- Store the sound file (σ:Φ) into the memory temporarily.
- Send sound file (σ:Φ) to the next component.
- Start the Cochlea (C) component.
- Do Filter (φ) function.
- Get the sound file (σ:Φ).
- Spot each sound signal in the sound file (σ:Φ).
- Insert each detected sound signal into the noise table (ν:Θ).
- Send noise table (ν:Θ) to the next component.
- Start the Brain (B) component.
- Do Recognize (Γ) function.
- Set the recognize (Γ) process as the intersection of noise table (ν:Θ) with the match table (μ:Θ).
- Therefore recognize (Γ) = (noise table (ν:Θ) ∩ match table (μ:Θ)).
- $\Gamma = (\nu{:}\Theta \cap \mu{:}\Theta)$ (1)
- Compare the records in the noise table (ν:Θ) with the records in the match table (μ:Θ).
- Retrieve the matched records.
- Update the records into the recognize table (Γ:Θ).
- View the records from the recognize (Γ:Θ) table as the definite sound (Ψ:σ).
- Do Learn (ε) function.
- Set the learn (ε) process as the intersection of complement (match table (μ:Θ))' with the noise table (ν:Θ).
- Therefore learn (ε) = ((match table (μ:Θ))' ∩ noise table (ν:Θ)).
- $\varepsilon = ((\mu{:}\Theta)' \cap \nu{:}\Theta)$ (2)
- Compare the records in the match table (μ:Θ) with the records in the noise table (ν:Θ).
- Find the unmatched records.
- Update the records into the learn table (ε:Θ).
- End.

Besides the formal step by step instructions, a general and formal algorithm to show the whole BISSA execution processes is made. This algorithm visualizes the effective method with the predefined input and the initial state as well as the instructions for a completing task. It also defines the series of successive states, and finally completes the process. Therefore the algorithm for BISSA is showed as follows:

```
START
BEGIN E
INSERT χ:σ → BISSA
DO [δ] (χ:σ) → σ:Φ
STORE σ:Φ → memory.temp
     END E
     BEGIN C
            GET σ:Φ ← E
            DO [φ] σ:Φ → σi, where ν = { σi }
            STORE ν = { σi } → ν:Θ
     END C
     BEGIN B
            GET ν:Θ ← C
DO [Γ] Γ = (ν:Θ ∩ μ:Θ)
STORE Γ → Γ:Θ
```

```
RETRIEVE Ψ:σ ← Γ:Θ
END [Γ]
                DO [ε] ε = ((μ:Θ)' ∩ ν:Θ)
STORE ε → ε:Θ
                END [ε]
        END B
END
```

In the direction of appreciating the symbols used in the block diagram for BISSA, the notations of Greek symbols are used for the system representations. It helps for the establishment of mathematical formula and system model.

TABLE II. NOTATIONS AND DEFINITIONS.

Notations	Definitions
σ	Sound
ν	Noise
Θ	Table
E	Eardrum
χ:σ	Complex Sound
δ	Detect
Λ	Load
σ:Φ	Sound File
C	Cochlea
φ	Filter
α	Arrange
ν:Θ	Noise Table
B	Brain
ε	Learn
ι	Identify
Γ	Recognize
μ	Match
μ:Θ	Match Table
ε:Θ	Learn Table
Γ:Θ	Recognize Table
Ψ:σ	Definite Sound

This research also clarifies the activities for BISSA in separate component. Moreover, the details specifications to describe the process are divided according to each component; eardrum, cochlea and brain.

A. *BISSA Eardrum Component*

E = δ. The input for E is complex sound (χ:σ). The processes are by inserting complex sound (χ:σ) into the system and store the sound file (σ:Φ) into the memory temporarily. Here, the output for E is sound file (σ:Φ). Then the sound file (σ:Φ) will be sent to the cochlea component for the filter process.

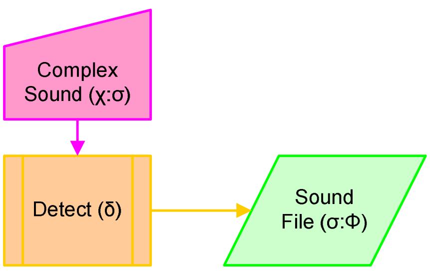

Figure 5. Detect Process

The example for this component; Initiate the process with dependent variables, e.g.

Match Table Records
Car, Motorcycle, Bus

B. *BISSA Cochlea Component*

C = φ. The input of C is sound file (σ:Φ). The processes are, get the sound file (σ:Φ), spot each sound signal in the sound file (σ:Φ), and then insert each detected sound signal into the noise table (ν:Θ). At this point, the output for C is noise table (ν:Θ).

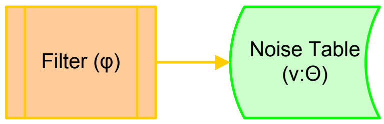

Figure 6. Filter Process.

Note that the σ = sound, ν = noise, σ:Φ = sound file, and ν:Θ = noise table. The σ can be σi, where σ:Φ → σi. Therefore the ν is the collected of many random sound signals, where ν = { σi }. With this, the ν will be updated into the ν:Θ, ν = { σi } → ν:Θ. For instance, the independent variables captured into the noise table, e.g.

Noise Table Records
Airplane, Car, Bus

The records in the ν:Θ will be set off to the brain component for the next process.

C. *BISSA Brain Component*

B = Γ + ε. Set the recognize (Γ) process as the intersection of noise table (ν:Θ) with the match table (μ:Θ), therefore, Γ = (ν:Θ ∩ μ:Θ). Set the learn (ε) process as the intersection of complement (match table (μ:Θ))' with the noise table (ν:Θ), hence, ε = ((μ:Θ)' ∩ ν:Θ).

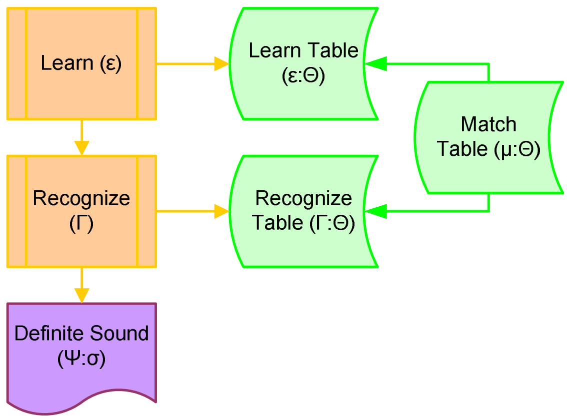

Figure 7. Recognize and Learn Process.

For Γ, the inputs are noise table (ν:Θ) and match table (μ:Θ). The processes are, compare the records in the noise table (ν:Θ) with the records in the match table (μ:Θ). Then retrieve the matched records and update the records into the recognize table (Γ:Θ). After that view the records from the recognize table (Γ:Θ) as the definite sound (Ψ:σ). The output for Γ is recognize table (Γ:Θ), definite sound (Ψ:σ).

Recognize Table Records
Car, Bus

For ε, the inputs are match table (μ:Θ) and noise table (ν:Θ). The processes are, compare the records in the match table (μ:Θ) with the records in the noise table (ν:Θ) and find the unmatched records. Then update the records into the learn table (ε:Θ). The output for ε is learn table (ε:Θ).

Learn Table Records
Airplane

With that the summarization of each components are as below:

- $\chi:\sigma \rightarrow (E + C + B) \rightarrow \Psi:\sigma$
- $E = \delta$
- $C = \varphi$
- $B = \Gamma + \varepsilon$
- $\Gamma = (\nu:\Theta \cap \mu:\Theta)$
- $\varepsilon = ((\mu:\Theta)' \cap \nu:\Theta)$

VI. CONCLUSION

As a conclusion the research on BISSA is made because the real system does not exist yet. This research analyzes of the biologically-inspired concept from the human ear and the human brain to develop BISSA. This research also commented the previous research made and updated the in a new version. The findings from this paper are a matching table to show the equivalent of the biologically-inspired entities to the computational process, a conceptual framework to show the capability requirements of the sound signal analyzer, a notation table to show the meaning of each functions, and a system model to show the capability functions of the sound signal analyzer. This research also comes out with an example of the vehicle sound analysis. This research is motivated by the human ear and human brain as a new idea to filter sound signal and to process data for information retrieval. BISSA brings many contributions and benefits such as for the oil and gas exploration, the medical purposes, and for the farming and plantations sector. As for the future work, this research will continue with the sound signal detection as well as the recognition and learning process with the implementation of fuzzy neural network to achieve it. Therefore, this paper describes the research objective which is to develop BISSA as a new idea for information gathering.

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