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محاكاة الحلزون السمعي الاصطناعي القابل للزرع: برنامج بحث وتدريب

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الملخص:

لعلَّ ما يطلق عليه طبياً بفقد السمع الحسي العصبي هو من أخطر أمراض الإعاقة السمعية إذ يؤدي إلى صممٍ تام نتيجة لعدم تنبيه العصب السمعي، كان العلاج مستحيلاً إلى حين ظهور جهاز الحلزون السمعي المزروع. في هذا البحث قمنا بمراجعة ودراسة مفصَّلة عن جهاز الحلزون السمعي المزروع وعزَّزنا ذلك بدراسة محاكاة عمله من خلال النموذج المصمَّم ضمن بيئة الماتلاب والذي يتيح لنا إمكانية إدخال الإشارة الصوتية ومعرفة آلية معالجتها ومن ثم سماعها كما يتلقاها المريض، ونظام المحاكاة هذا مُعَدّ ليكون برنامج محاكاة شامل بغرض السماح بالمحاكاة وفقاً لمزايا مختلف أنظمة الحلزون المزروع المتوفرة في الأسواق أو حتى وفقاً لمزايا أنظمة غير متوفرة في الأسواق، إلا أن الضجيج وعدم الجودة الكافية لأدوات اقتباس الإشارة الصوتية بالإضافة إلى عدم وجود الوقت الكافي للاستفادة من جميع الإمكانيات التي يوفرها الماتلاب بهدف تحسين معالجة الصوت أو حتى تصميم عدة نماذج لتقنيات معالجة الإشارة والمقارنة بينها واختيار الأنسب كان من أهم الصعوبات التي واجهتنا، ولكن تمكنا في نهاية البحث من إجراء المحاكاة واختبارها ويمكن الآن توفيرها كمنهجية للتعلم في فهم مبدأ الحلزون السمعي الصناعي المزروع وكذلك للأبحاث والاختبارات لمختلف نظم الحلزون السمعي الصناعي المزروع.

تاريخ الايداع
تاريخ القبول

في هذا البحث قمنا بدراسة مفصَّلة عن جهاز الحلزون السمعي المزروع وتقنيات معالجة الإشارة المعتمدة في أجهزة الحلزون وتطورها مع الوقت، لننتقل إلى بناء نموذج محاكاة ضمن بيئة الماتلاب يوفر لنا محاكاة لعمل الجهاز من خلال إدخال إشارة صوتية ثم معالجتها مع توضيح لكافة المراحل التي تمر بها الإشارة الصوتية إلى أن يستقبلها المريض، ويتيح لنا هذا النموذج المقترح إمكانية سماع الإشارة الصوتية التي يتلقاها المريض، والتي يُقرَّر على إثرها الحاجة إلى إجراء تعديلات على النموذج أو عدمها.

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Simulating an implantable artificial auditory helix: A research and training platform.

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Abstract:

Sensorineural hearing loss is an extremely serious disease of the hearing system, and leads to complete deafness until the manufacturing of a replacement of the auditory nerve; which is the implantable auditory helix device. Computer simulation of the helix and its operation allow researchers and students alike to be able to study the various parameters that influence the performance of the helix. MATLAB environment is used, which allows the possibility of presenting a research and training platform. It has become feasible now to apply various audio signals and speech situation to the input of the helix, and knowing the mechanism of processing it, and then hearing it as the patient receives it. This simulation system is intended to be a comprehensive simulation program to allow investigating the various implanted cochlear systems available on the market or even those systems that not available on the market yet. It allows the of various types and magnitudes of the noise and interference at the input of the helix and at its different stages. Utilizing all the capabilities which MATLAB provides to improve sound processing or even design several models of signal processing techniques, comparing them and choosing the most appropriate ones is also provided. It also feasible to conduct and test the simulation.

In this research, we proposed a simulation model using the MATLAB environment. This model not only simulates the various parts of the helix, but allows the introduction of different audio signals and speech situations combined with all kinds of noise that might accompany the speech. provides us with a simulation of the device's operation by entering an audio signal and then processing it with an explanation of all the stages that the signal goes through. This proposed model allows us to hear the audio signal that the patient receives, after which it is decided whether or not to make adjustments to the model.

Received:
Accepted:

Keywords: cochlear implant surgery, climatic effects on helix, residual hearing after cochlear implant surgery.

1. Introduction:

The combination of engineering and medical sciences has led to finding solutions to many complex health problems, the most prominent of which are hearing disorders that hinder a person’s communication with his surroundings. Traditional medical hearing aids were a treatment for conductive hearing loss resulting from a defect in the outer or middle ear, which impedes the transmission of mechanical vibrations to the inner ear. The work of hearing aids is limited to amplifying sounds. As for sensorineural hearing loss, which results from a lack of stimulation and auditory nerve as a result of damage to the hair cells in the ear. The inner ear led to the idea of electrical stimulation of the remaining healthy nerve cells directly, but speech was not initially understood by the patient. With the development of techniques used for auditory stimulation, a patient became able to understand speech well, and the efforts of researchers in sciences such as medicine, sound, and signal processing were fruitful with the emergence of a prosthetic device that contributes to restore hearing to a deaf person. It is the implanted hearing helix device, which stimulates healthy nerve cells. The biggest challenge for the success of the implanted helix device was how to stimulate the neurons appropriately to deliver useful information about the sound signal that can be perceived by the brain.

2. If we want to provide a simple definition of the implanted auditory helix, it is a device that extracts the sound signal from the external environment via a microphone and analyzes it using an audio analyzer or so-called speech processor to encode the information contained in the speech signal and convert it into electrical impulses to stimulate the auditory nerve, and thus it simulates in its work normal helix action in the inner ear.

3. Literature Review:

In 1995, Shannon performed a simulation that focused on the amount of spectral and temporal information required to perceive speech. This simulation divided the signal into four frequency bands, and the envelope in each band was extracted using a half-wave rectifier and a low-pass filter (various cut-off frequencies were applied and tested). The envelopes were organized and filtered. Noise using the same bandpass filters that were used in the analysis phase of processing and all bands were collected and presented over the speakers. The stimulus included medial consonants (a consonant between two vowels), vowels and simple sentences, after training on all sounds, eight listeners were asked to discriminate each stimulus. Differences in low-pass cut-off frequencies did not affect significant performance differences. Designed to record high speech perception (90% correct word recognition), this perception can be achieved using three analysis channels.[3] In 1997, Dorman performed a similar simulation, but he researched using sine tones in addition to band-limited noise, and the number of channels varied between 2-9. When the number of analysis channels increases, recording for understanding vowels is approximately reached at eight channels, while for understanding sentences, five channels are reached Enough.[3] In 1999, Loiseau used a simulation to examine the number of channels needed to understand speech with multiple speakers. The stimulus included phonetically rich sentences. Five channels were needed to achieve 90% correct recording. On the other hand, the results were similar using eight channels. This simulation included situational information not included in the Treatment of transplanted auditory helixes.[3] In 2000, Weiss completed the most detailed simulation in which he simulated not only the signal processing of the auditory helix implant but also some of the perceptual limitations associated with hearing impairment. His simulation was used to evaluate people's results on speech comprehension tests, and the results were similar to those performed on listeners with auditory helix implants.[3] In 2009, a simulation study was conducted in the Department of Medical Engineering at the University of Damascus on the operation of a multi-channel snail device (with four channels) to obtain a bachelor's degree in medical engineering, prepared by students Raghad Sawaf, Muhammad Al-Quwatli, and Walid Shehab. This was through a practical application containing two programming sections. electronic and the software section includes a simulation program for the audio signal processor based on the LABVIEW program, while the electronic section includes the wireless transmission circuit and the reception and excitation circuit, and the work of the electrodes was simulated through photodiodes.[3] In 2018, a study was conducted for the computational evaluation of the outcomes of cochlear implant surgery (CI). The study aimed to study the results of computational models, taking into account the uncertainty in the parameters and their variability, to predict the neural response to support optimization processes for surgical planning and implant design, through several steps, first studying the results of the CI. In a virtual population using the MC method, due to the large amount of time required to study uncertainty, the HTC environment is used to significantly reduce the total time of computational analysis and then the focus is on implant performance in a patient-specific case using PCM, This reduces the time required to search for optimal stimulation levels provided by the implanted electrode (a time-consuming process), providing appropriate preparation for programming the implant in the particular patient during the post-intervention procedure.[5] In 2021, the climatic effects of temperature and humidity on the operation of the cochlear implant and the quality of the electroacoustic signal were studied. A MATLAB Simulink simulation was prepared, which provides insights into the behavior of the signal under these changes in climatic parameters. The simulation setup for the cochlear implant was developed using Selecting the source type to change between audio recording and CHRIP audio, in addition a DC filter was applied to the input signal, and then a simulation code was developed with the climate effect applied via an air attenuation function Therefore, the temperature and humidity attenuation in the acoustic envelope rotation of the input signal at (T=0°C and RH=0%) and at (T=36°C and RH=40) was represented graphically. Electrical pulse generator results were obtained for each of the eight channels with IIR filter, Gaussian noise, temperature and humidity variation, and denoising block activity control.[6] In 2023, finite element modeling of residual hearing after cochlear implant surgery was performed in Chinchillas. The research presented a finite FE model of the Chinchillas inner ear to study the interrelationship between mechanical function and CI electrode insertion angle. This model includes a three-chamber cochlea and a complete vestibular system and is accomplished using techniques μ-MRI and μ-CT scanning. The first application of this model found minimal residual hearing loss due to insertion angle after cochlear surgery, suggesting that it is a reliable and useful tool for future applications in Tympanic membrane design, surgical planning, and stimulator preparation.[7]

4. Material and Methods:

5. **Parts of the cochlear implant:** It consists of two parts: an external part located behind the ear and an internal part that is surgically placed under the skin. In general, it consists of:
6. **1- Microphone:** It picks up sound from the environment.
7. **2- Speech processor**: which selects and arranges the sounds that the microphone picks up.
8. **3- Transmitter and Receiver/Stimulator:** Receive signals from the speech processor and converts them into electrical impulses.

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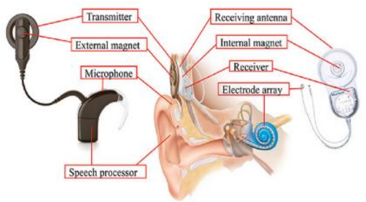
9. **4- Electrode array:** It is a group of electrodes that collect impulses from the stimulator and send them to different areas of the hearing nerve. [8]
10. The figure below shows the main components of a cochlear implant:
11. 

Figure(1) Parts of the cochlea. [8]

12. How cochlear implants work:

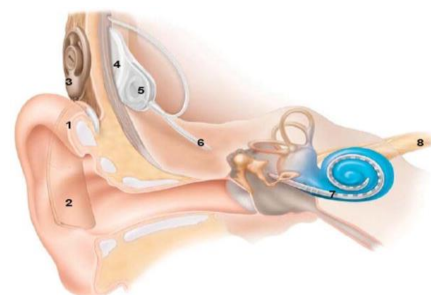
13. The primary goal of a cochlear implant is to safely use electrical stimulation to provide or restore functional hearing. Figure 5-3 graphically shows a typical modern cochlear implant system. The external behind-the-ear processor with a hook and battery pack (2) uses a microphone to capture sound, convert it into a digital signal, process the digital signal, encode it (encrypt it) into a radio frequency (RF) signal and send it to the antenna inside the headpiece (3). The headpiece is then installed in Placed by a magnet attracted to an internal receiver (4) placed under the skin behind the ear, the hermetically sealed stimulator (5) contains active electronic circuits that derive energy from the radio frequency signal, it decodes the signal, converts it into electrical currents, and sends it along wires (6) interconnected in the cochlea. The electrodes (7) at the end of the wire stimulate the auditory nerve (8), which is connected to the central nervous system. It must be noted that these electrodes are activated based on frequencies The audio signal, those in the base area are excited with high frequencies (non-vocal signal), while the electrodes in the apex area are excited with low frequencies (vocal signal), and then the electrical impulses are interpreted as sound. The number of healthy nerve fibers and their rate of excitation affect the loudness and loudness of the sound. The greater the number, the louder the sound, and vice versa, The loudness of the sound can be controlled by different amplitudes of the excitation current, so we can say that the implanted auditory auditory helix device transmits information about the loudness of the sound, which is indicated by the amplitude of the excitation current, and information about the frequency of the audio signal, which is indicated by the location of the electrodes.[4]
14. 

Figure (2) How cochlear implants work.[4]

Figure (3) shows a box diagram showing the mechanism of operation of the implanted auditory helix hearing device, which we explained earlier.

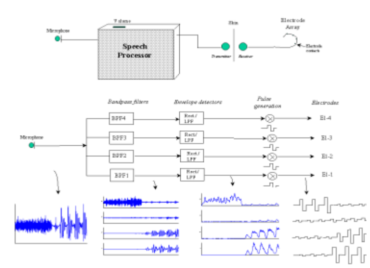


Figure (3) is a box diagram showing the mechanism of operation of the cochlear implanted hearing device.[4]

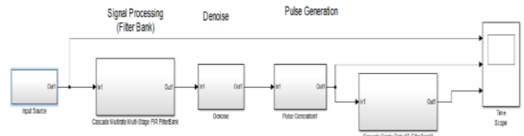
15. **Multi-channel cochlear implant:** A multi-channel cochlear implant was developed rather than a single channel because electrophysiological research has shown that single-channel stimulation

cannot reproduce the high speech frequencies essential for speech understanding. The first commercial multi-channel cochlear implant was tested on a human participant in 1982, setting off the path of hearing implant innovation worldwide, with the US Food and Drug Administration (FDA) approving Cochlear Limited's Cochlear Nucleus 22 implant system (for use in adults). Those suffering from profound sensorineural hearing loss in 1985 AD. [2]

16. Practical application and its results:

17. Simulating an implanted auditory helix is a software application that allows us to simulate how sound is received by a person undergoing a auditory helix implant. One of the functions of this application is to read an audio file in waveform or record an audio signal using the computer's microphone input. It is possible to configure the elements used for the simulation and simulate many in some cases, in addition, we can obtain a new audio signal from an original signal (a saved audio file or audio recording), This new signal is synthesized according to the selected simulation elements, and represents how the original auditory signal would be received by the patient. Conducting this simulation process ultimately allows us to obtain the best possible system for the implanted auditory helix after studying all cases and taking into account all influencing factors. We have studied the model applied within the MATLAB environment, which is prepared to simulate a 16-channel helix device, explaining the mechanism adopted in this simulation and the elements used.

18. Cochlear implant model:

19. 

Figure(2) Simulation model of a cochlear implant.

20. The model consists of the following basic blocks:
21. 1- Input source block.
22. 2- Filter Bank (Signal Processing).
23. 3- Denoise block.
24. 4- Pulse Generator block.

25. Input source block:

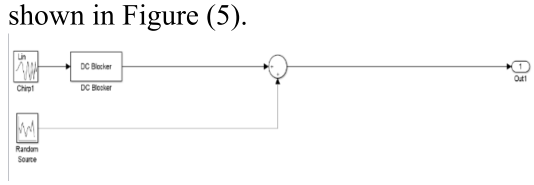
26. The task of this block is to generate the audio signal that is considered an input signal for the implanted auditory helix's auditory device.
27. **To determine the type of audio source:** The type of signal used here is Chrip, which means the audio signal whose frequencies increase little by little. Microphone signal. We can use other types, such as the speech signal, and one of the options may be to choose a sound signal (Y) to be read from the workspace (Signal from the workspace), but we only relied on the Chrip signal in this model. This is shown in Figure (5).
28. 

Figure (5) Input block.

29. **Adding noise to the generated audio signal:** This is done by adding a little noise to the input signal using Random Source, which is a random intermittent signal whose amplitude is between (+0.1_-0.1), to take into account the noise that will be associated with the signal received from the surrounding environment in the actual cochlear implant device.
30. The input signal is as shown in Figure (6).

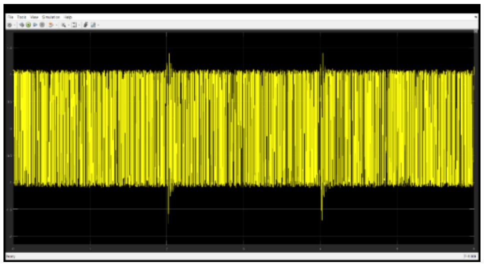


Figure (6): Input signal format.

Data processing methods adopted in the model: Filters block (signal processing): This block is similar in its work to the work of the audio analyzer that we talked about previously, as it filters the incoming audio signal and analyzes it into a group of frequency bands. In the studied model we have 16 frequency bands, as the auditory helix device. The one simulated is 16 channels. The filters used in this block are digital filters. The block of filters that process and we note from the model in Figure (4), consists of:

31. Cascade Multi-rate Multi-Stage FIR Filter Bank: which contains within it the FIR finite impulse response filter and the Rectifier, as shown in Figure (7)

Block of filters in the model. Figure(7)

32. We divided the **FIR** filter into Two-Channel Analysis, shown in Figure (8), which distributes the signal into two parts: a Low Pass Filter and a High Pass Filter, which pass high and low frequencies. These filters are of the sixth order due to the presence of six coefficients to each their own.

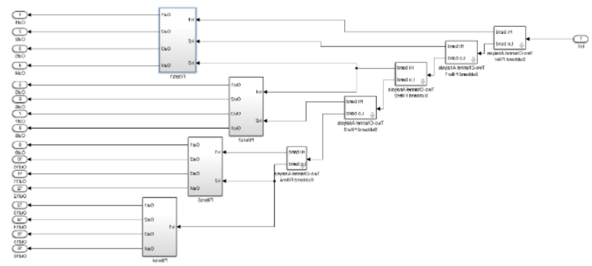
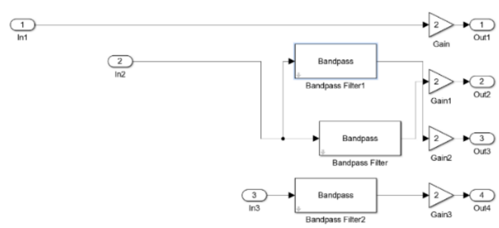
33. 

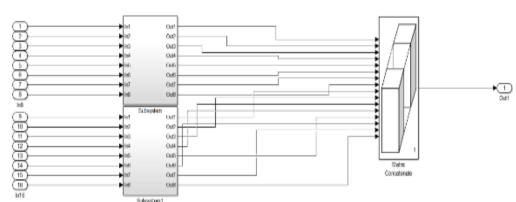
Figure (8) FIR filter design.

34. As for the filters, Filter1, Filter2, Filter3, and Filter4, they are filters that contain bandpass filters that work to pass frequencies between two specific values. The four filters differ from each other in the gain factor values only. Figure (9) shows the internal layout of the Filter1 block, which includes a gain factor of 2.



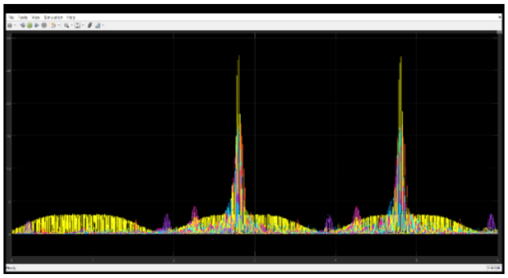
The internal layout of the Filter1 block, which includes a gain factor of 2. (Figure(9)

35. **Rectifier:** It is a wave rectifier, which we use to obtain a signal in one positive direction, for example, through absolute value (Abs), and then we combine the signal using Matrix Concatenate.

36. 

Internal design of the Rectifier. Figure(10)

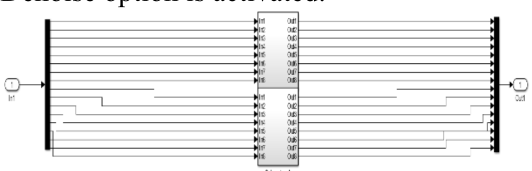
37. Figure (11) shows the shape of the signal after it exits the filtering unit.

38. 

The shape of the signal after it exits the filtering unit Figure (11)

39.Noise removal block:

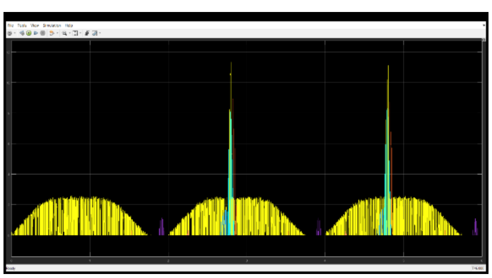
40. The task of this block is to reduce noise, or rather to remove signals with low amplitudes, and to pass only signals whose amplitude in absolute terms exceeds the values at both ends of the dead zone. The signals in each of these channels pass through a different dead zone when the Denoise option is activated.

41. 

Noise removal block Figure(12)

42. Figure (13) shows the shape of the signal after it exits the noise removal block.

43.

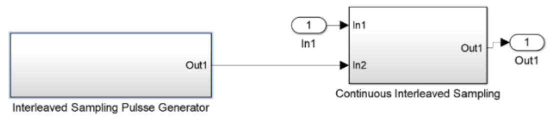
44. 

45. The shape of the signal after it exits the noise removal block. Figure (13)

46.Electrical pulse generation block:

47. The task of this block is to generate asynchronous electrical pulses that will alert the different areas of the auditory helix and modify the signals received from the various channels according to these pulses. It consists of two blocks, as shown in Figure (14):

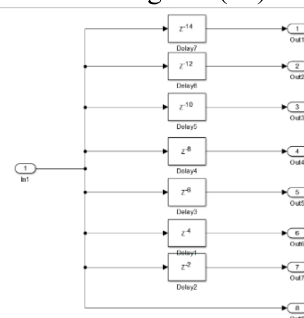
48. Interleaved Sampling Pulse Generator block
49. Continuous Interleaved Sampling (CIS) block



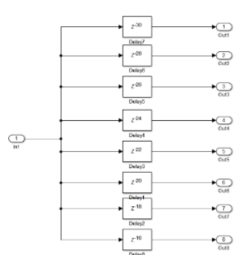
50.

51. Figure(14) Pulse generation block.

52. The first block generates electrical pulses on 16 channels, and the pulse in each channel lags behind the channel that precedes it by z-x, and the value of x is what determines the number of samples that will be kept in each Delay, and here it is by two cycles, that is, asynchronously. We notice the presence of two Subsystem blocks, each of which contains 8 blocks. Delay, as shown in Figures (15) and (16).

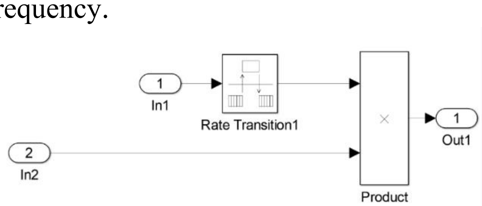
53. 

54. The first subsystem block. Figure (15)

55. 

56. The second subsystem block. Figure (16)

57. As for the second block shown in Figure (17), which represents one of the techniques adopted in multi-channel audio auditory helix devices, which is CIS, it works to modify the signals of the 16 channels coming from the filter block by multiplying the signals of each of them with the signals coming from the pulse generator so that we get a result for each sample. Two pulses, one of which has a positive amplitude and the other has a negative amplitude. This amplitude is equal to the amplitude of the sample corresponding to this pulse and coming from the filter block. We notice in the figure the Rate Transition element, which works to harmonize the blocks, each of which operates at a different cutting frequency.

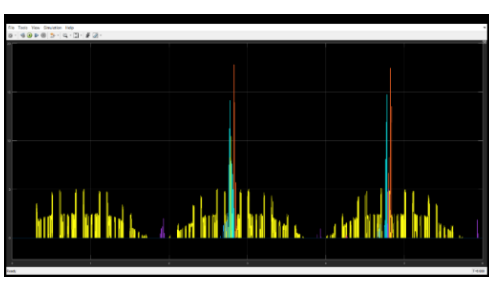


58.

59. Figure (17) The second block of the pulse generator.

60. The shape of the signal after it exits the pulse generation block is as follows

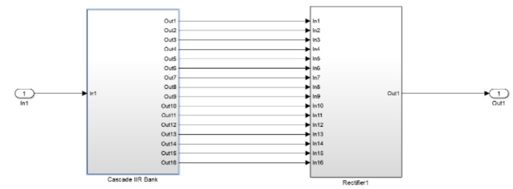
61.



62.

63. Figure(18) The shape of the signal after it exits the pulse generation block.

64. **IIR filter:** This is similar in operation to the FIR filter but is similar in design according to Figure (19), that is, it returns the signal to a form that we can hear and see.



65.

66. Figure (19) IIR filter structure.

67. Thus, the simulation of the work of the implanted auditory auditory helix has been completed, but the MATLAB program provides us with the possibility of regenerating the speech signal in one of two ways: sequential or parallel. It is possible to regenerate it by re-filtering the signals multiplied by the resulting (modified) electrical pulses using infinite impulse response filters. Which we talked about previously, and then the filtering products are collected, and here the signal is generated serially from the different channels or the non-multiplied signals are re-filtered with electrical pulses (unmodulated), then the filtering products are collected, and here the audio signal is generated from the different channels in parallel, and all of that is done. Through the block of regeneration of the speech signal from the generated impulses.

68. x generation block. The list represents the output.

69.Results and Discussion:

Figure (20) shows a comparison between three signals. The first signal is the input signal that was entered into the system. The second signal represents the shape of the signal after it exits the pulse generation block. The list represents the output of the last stage after filtering, i.e. Expresses the final signal.

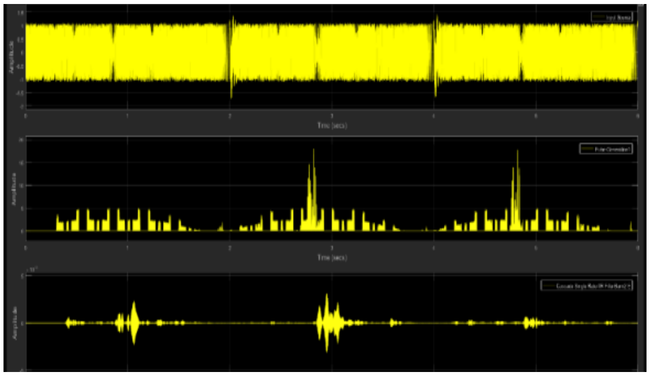


Figure (20) comparison between three signals. The first signal represents the input signal that was entered into the system. The second signal represents the shape of the signal after it exits the pulse generation block. The list represents the output.

Conclusion:

Further investigation is necessary to be conducted and the system tested to come up with a robust platform and investigating two important signal-processing technologies, namely CIS and SPEAK, and developing more algorithms that enable to reduce noise better. By identifying the factors that cause differences the performance among patients, it can lead to developing signal-processing techniques in a way that matches the requirements of each patient.

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