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Self-Fitting Hearing Aids: State of the Art, Challenges, and Future Trends

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Abstract

The global aging leads to a dramatic increase in the demand for hearing aid. However, the lack of hearing care institutions and hearing professionals makes high price of hearing aids, which hinders the widespread use of hearing aids, especially in the developing countries and the remote areas of developed countries. Compared to the teleaudiology, the self-fitting hearing aid can be installed, fitted, and managed by the users themselves. The whole process hardly needs any professionals and special equipments. Although the research of self-fitting hearing aids is in its infancy, it has significant theoretical value and application prospect. At present, except for some commercial attempts to the self-fitting hearing aids, there are still some problems to be imminently solved. In this survey paper, an overview of the state of the art and prototype design for the self-fitting hearing aid is provided. Then, the challenges for self-fitting hearing aids are discussed. Finally, the future trends of self-fitting hearing aids are prospected.

Keywords: *Hearing aids; self-fitting; audiometry; cognition*

1. Introduction

According to the world health organization statistics, the number of hearing-impaired patients is more than 270 million and hearing impairment has been the third chronic disease [1]. In addition, hearing rehabilitation is facing more severe challenges due to the global aging [2]. Long time hearing impairment not only affects normal conversation, comprehension ability and pronunciation skills but also leads to loneliness and grumpiness. Even worse, some patients will have psychological barriers or alzheimer's disease which will bring negative influence to their family and the whole society [3]. At present, wearing a hearing aid is one of the most effective means of hearing rehabilitation [4].

However, even in developed countries, only one in five people has hearing aids [5]. Affected by the medical conditions and people's lower health care consciousness, this proportion in developing country is much lower [6]. A number of studies show that the reason is high price, discontent with the performance of hearing aids under noisy environment and higher demand for hearing service(relative to the developing countries) [7]. There are mainly two factors that influence the utilization of hearing aids in developing countries: 1) The price. The price of a hearing aid should be as cheap as what a normal family can afford [8]. So, the world health organization suggests that the price of a hearing aid should be consistent with the personal income of a country. 2) Lack of hearing professionals. The three basic processes of traditional hearing aid fitting are: a clear description of user's problem, correct interpretation of the problem, and transform the problem into appropriate electroacoustic parameters of the hearing aid. These

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processes depend on the skills of the hearing professionals. When problem arise, hearing patient firstly seek help from their hearing professionals even though the problem is very small. This undoubtedly wastes a lot of time. In addition, qualified hearing professionals in developed and developing countries are all woefully inadequate. The outflow of talented hearing professionals make related services of hearing aids in developing countries lag further behind developed countries, which restricts the development of hearing aids and increase the additional cost in developing countries indirectly [9].

Teleaudiology is an effective solution to the problem of lacking hearing professionals [5]. This technology is mainly applied in the remote hearing diagnose, hearing test, regulation and consultation for hearing aids. It can effectively overcome some shortcomings, such as long distance, high cost, and lack of professional institutions in remote areas and increase accesses to hearing services [10]. Surveys show that 75 percent hearing-impaired patients with moderate to extremely severe hearing loss are more willing to remote hearing service [11]. Unfortunately, since doctors and patients may come from different countries, there are many urgent problems to solve, such as qualification, responsibility, reimbursement, quality control and so on. Besides, the establishment and maintenance of hearing networks still depends on professionals. The professionals can assist patients to obtain information and guidance. These problems have seriously affected the development speed of American teleaudiology [12]. With the wide penetration of smart phones, teleaudiology is bound to become the access point to provide services, which include information, education, screening, possible diagnosis and intervention [13-15].

From the design conception, self-fitting is the best choice to solve the problem of lacking hearing professionals [16]. The essence of self-fitting is that the installation, fitting and usage of hearing aids are completed by the user himself without any hearing experts and equipment. In 1984, Köpke, Wiener, *et al*,. mentioned that pure tone signal generated by pure tone generation inside the hearing aid could be used to measure the patient's hearing threshold, and a transfer function is designed to generate suitable configuration parameters for hearing aids[17]. This is the basic conception of self-fitting hearing aids, which hasn't been achieved till today. But some primary products of self-fitting hearing aids have come out which is based on one point that using hearing aids without professionals. These products are mainly divided into two categories: user-programmable hearing aids and customized hearing aid for developing country. In addition, around the commercialization of self-fitting hearing aids, the design of professional instruction materials [18] and the research of ear molds, batteries and distribution models, *etc.*, are being carried out simultaneously. However, how can patient without little professional knowledge make effective diagnosis towards some problems, such as how to identify asymmetrical hearing loss, conductive hearing loss or sudden hearing loss caused by earache, physiological ear deformity or active infection? All these problems will affect the fitting. Whether Hearing aids can solve these problems has a lot of unknowns and need to be further studied.

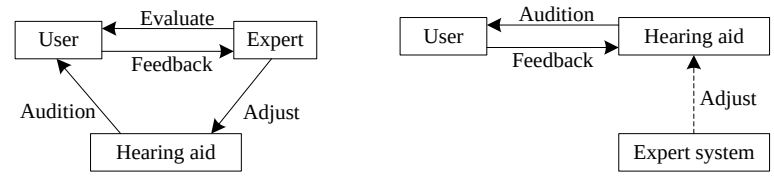
In 2011, Lena L. N. Wong summarized the four characteristics of self-fitting aid and assess it using six-level criteria [19]. Results show that two kinds of technology for self-fitting hearing aids have been relatively mature: 1) Hearing aid can automatically assesses the patient's hearing level; 2) Traditional fitting methods will obtain the parameters which are similar to the initial set as patient like. However, whether a patient can get better results by training or complete the assembly and use of hearing aids under the prompt, the current study is still insufficient.

According to the research for self-fitting aids, this paper describes the design concept, prototype theory and the current developments of self-fitting hearing aids in detail, overviews the latest theoretical results and applied research related to self-fitting aids, describes the research progress in the world, discusses the open issues, and focuses on the future direction of self-fitting hearing aids.

2. Basics of Self-Fitting Hearing Aids

2.1. Process of Self-Fitting

Fitting is vital for hearing aids. Because hearing, cognitive level and personal habits of each patient is different, every hearing aid is supposed to be unique and exclusively personal. So fitting a hearing aid is similar to fitting a pair of glasses, but it is more complex and demands higher skills. Figure 1, shows comparisons between traditional fitting and self-fitting for hearing aids. Figure 1, (a) is the traditional fitting process and Figure 1, (b) is the self-fitting process. From the Figure, it is obviously that experts play a very important role in the traditional fitting. They must have rich professional knowledge about hearing aids and audiology. First of all, audiologists must overall assess patients' hearing level to select the appropriate hearing rehabilitation equipments and schemes. Secondly, they must interpret the feedback from patients to adjust parameters of hearing aids. Finally, they also need to determine the adjustment extent based on their own experience. Therefore, for traditional hearing aids, skills and experience of experts are the main limitation for the performance of a hearing aid, which is also one of the most important reasons that affect the popularity of hearing aids in developing countries.



(a) Traditional Fitting Process (b) Self-fitting Process

Figure 1. Fitting Process of Hearing Aids

From Figure 1, (b), the self-fitting hearing aid can interact directly with hearing-impaired persons without audiologists. The optional expert system can partly act as an expert based on the artificial intelligence algorithm. The realized function includes the Initialization and update of parameters, the measurement of hearing and so on. However, the related research is still relatively few. In addition, taking into account portability, human-computer interaction tends to be wireless, which brings more power consumption.

2.2. Design Prototype and Related Products

Over the years, scholars generally believe that the self-fitting hearing aids should have four characteristics [20]: 1) the automatic evaluation of hearing threshold to generate initial settings; 2) training hearing aids based on the user's preferences; 3) training hearing aids without audiologists; 4) assembling and using hearing aids without audiologists.

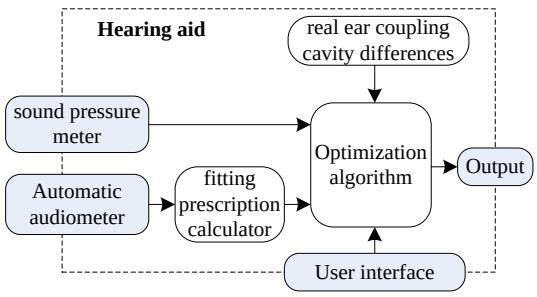


Figure 2. Prototype of Self-Fitting Hearing Aids

From the characteristics of self-fitting hearing aids, there are significant differences in user interaction between self-fitting hearing aids and traditional hearing aids. The self-fitting hearing aids contain more features and more complex algorithms, such as automatic audiometer. In 1984, Köpke, Wiener *et al* defined the basic concepts of self-fitting hearing aids at first. As shown in Figure 2, the initial prototype contains five basic components: automatic audiometer, sound pressure gauge, fitting prescription calculator, real ear coupling cavity differences and the user interface. The automatic audiometer is used to assess a patient's hearing loss. The fitting prescription calculator is used to calculate the initial parameters of the hearing aid based on hearing loss estimated by the automatic audiometer. The sound pressure gauge can assess the current sound pressure levels to instantly adjust loudness compensation parameters. The real ear coupling cavity difference is subtracted from the measured gain with hearing aids to achieve the real gain. The user interface is used to receive feedback information of the patient and accordingly adjust parameters of hearing aids.

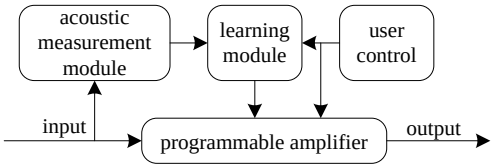


Figure 3. Structure of User-Programmable Hearing Aids

Currently, the research of self-fitting hearing aids in US National Acoustic Laboratories mainly includes three parts: the self-test of hearing, programmability, and the applicability in developing countries. Although early studies have technical limitations, the development of related technologies makes self-fitting hearing aids possible, such as automatic hearing measuring through integrated pure tone generator and quick human-computer interaction by wireless module. Moreover, more complex and powerful digital hearing aids chip makes complex transfer function, fitting formulas and training algorithm become feasible. Therefore, although the commoditization of self fitting hearing aids is still far away, two kinds of similar products are formed according to design conception of US National Acoustics Laboratory [16]: user-programmable hearing aids [21] and customized hearing aids for developing countries [1-6]. But these two kinds of products are only similar to the self-fitting hearing aids.

2.3. Accessories of Self-Fitting Hearing Aids

2.3.1. Automatic Audiometer: Whether ordinary hearing aid or self-fitting hearing aid, it is of great significance to obtain a comprehensive and accurate hearing assessment for patients. The hearing condition of hearing-impaired persons is generally represented by audiogram, which is traditional measured by audiologists. For self-fitting hearings aid users, the audiogram is obtained by themselves. Studies show that the self-evaluation of patients is beneficial [22-23]. Therefore, the key point of self-fitting hearing aids is the validity and reliability of automatic measured in-situ threshold (so-called audiogram) [24], which is often accomplished by automatic audiometer shown in Figure 2. Theoretically, any information of patient is unknown for a self-fitting hearing aid in its initial state. Only by measuring the hearing condition of a patient, the self-fitting hearing aid can obtain the hearing estimation of the patient, and then calculate the initial parameter based on prescription formula.

Currently, automated hearing screening or diagnostic assessment have been more accurate and efficient [25-26]. For both adults [27] and children [28], the automatic threshold measurements show that auxiliary air conduction audiometry is as accurate and reliable as manual measurements. In addition, the National Acoustic Laboratories found

that [24] the threshold measurements will be more reliable and efficient if complex decision rules are transplanted into a hearing aid. However, measurements of bone conduction audiometry are more accurate. Subjects should be children or persons who are difficult to test and test items should include the type and extent of hearing loss [29].

Although on site measurement is as reliable as traditional methods [30], there are still several problems need to be further studied. These problems include the selection of measuring mode, the appropriate transducer with a wide range of threshold levels [31], ambient noise control under threshold measurement [32-33], self-management program for identifying asymmetric and conductive hearing loss.

2.3.2. Human-Machine Interaction Interface: The core feature of a self-fitting hearing aid is that patients can adjust the hearing aid parameters themselves according to the environment so that to obtain the best performance of hearing aids. Although parameters of current hearing aids can be adjusted by buttons and knobs, it is unrealistic for increasingly complex algorithms. So it is necessary to design the effective user interface. With the development of smart phones, future self-fitting software should be installed on some terminals like smartphone or PDA [34]. With the application of Apple's FaceTime or Microsoft's Skype, video telemedicine can be implemented based through phones and tablets. The utilization of high-resolution cameras, domestic remote sensors, such as infrared sensors, video surveillance cameras and medical monitoring sensor, makes telemedicine services be a mainstream [10]. Especially in ototoxic medication regimens, because patients should be regularly monitored, household equipments are essential to assess the hearing of the patient [35].

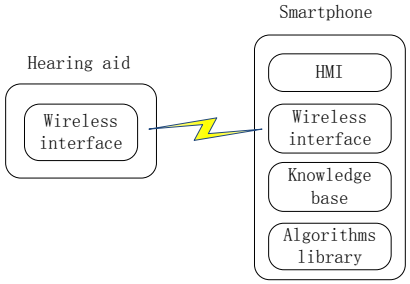


Figure 4. Structure of Intelligent Terminals

As shown in Figure 4, intelligent terminals should contain four parts: wireless interface, human machine interface(HMI), knowledge base and algorithms library. With the development of wireless technology such as Bluetooth and Wifi [36], more and more hearing aids integrated wireless technology. The innovation of wireless technology provides great convenience for the realization of self-fitting hearing aids[35]. Firstly, not only command but also speech can be transmitted between the fitting terminal and hearing aids. Secondly, it helps to realize the design conception of '3W', namely whatever, whenever and wherever [34]. For HMI, except functionality and user friendliness, simplification is also important. How to achieve the best results with minimum operations is critical to HMI design, especially for elderly patients and persons who are not convenient to operate. If speech recognition technology is integrated in hearing aids, it will play a major role in the promotion of self-fitting hearing aids. In the future, the audiologist can be partially substituted by knowledge base. The initialization, update and optimization of parameters can be accomplished through some artificial intelligence algorithms based on hearing condition and individual characteristics of patients. The implementation of intelligence algorithm is relatively complex, which needs to be further studied. Finally, the algorithm library integrates a number of fitting formulas and

algorithms, which can be used to generate the test sound and update algorithm parameters according to the feedback of patients.

3. Advantages and Disadvantages

The value of self-fitting hearing aids has long been controversial. A questionnaire survey for elderly patients in developed countries shows that the majority of patients considered that self-fitting hearing aids are desirable [37]. Results show that 83% of the subjects think that self-fitting hearing aid is a good idea. From the survey, patients doubt that whether the level of their professional skills and expertise are capable to meet the requirement of fitting a hearing aid independently. However, the self-fitting hearing aids have three prominent advantages: 1) Low price. Prices are the main factor which affects the promoting of hearing aids, which is more obvious in developing country. From design principles, self-fitting hearing aid can be operated with no audiologist and few consultation to the hearing institution, so that the additional cost of hearing aid services will be greatly reduced which also leads to lower prices of hearing aids. 2) High environmental adaptability. Among the factors affecting the usage of hearing aids, poor environmental adaptability is a common problem. The benefit of self-fitting hearing aids is that patients can adjust parameters according to the current environment by themselves. The basis of the adjustment is patient's feedback, which is closer to the concept of self-fitting hearing aids, and therefore gets better performance.3) Enhanced awareness of patients' psychological ownership. When fitting their own hearing aids, patients' sense of ownership is accumulating and deepening. This feeling stimulates patients' interest in hearing aids, and thus helps patients understand hearing aids and their own problems, which contributes to obtain best performance of hearing aids.

Although self-fitting hearing aids have obvious advantages, there are still some technical problems. Firstly, in terms of the constitution of self-fitting hearing aids, although the automatic measurement has been more accurate and reliable, it is not suitable for all users and still needs professional supervision. Incorrect measurements can lead to inappropriate gain which impacts the effectiveness and patients' satisfaction. Secondly, from the viewpoint of test content, the extent and type of hearing loss are all determined according to their hearing threshold. Unfortunately, the way to detect asymmetrical hearing loss, conductive hearing loss or mixed hearing loss by hearing aids has not come up yet. This is one of major constraints of self-fitting hearing aids. Only when doctors recommend a patient to wear a hearing aid, he would consider buying a self-fitting hearing aid. In this case, to some extent, the self-fitting hearing aids may not determine whether a patient is suitable for wearing hearing aids. Thirdly, with increased automation, fitting algorithm inevitably becomes more complex. Traditional fitting requires several interactions between experts and patients, and it demands increasingly higher skills of audiologist, which has become an important factor to restrict the use of hearing aids [38]. The use of intelligent algorithms to replace the role of audiologist has become a research trend. Therefore, the design of a more efficient parameter optimization model and algorithm needs further study.

4. Summary and Prospect

The design conception of self-fitting hearing aids is widely recognized by the users [37], but there are still many problems to be further studied. Potential improvements involve many aspects, such as accessories and processes of hearing aids, algorithms, the relation between cognitive ability and hearing aids. Since subjects of self-fitting hearing aids are the patients themselves, the design principle of such a hearing aid is customized, namely designing hearing aids according to the physical and psychological characteristics of the patients.

4.1. Accessories and Processes of Hearing Aids

Although the installation, debugging and usage of a self-fitting hearing aid are completely dominated by the user himself, the physical structure and pathological condition of patients is different. How to personalize the accessories of hearing aids is necessary and difficult to tackle. If there are some malleable materials, it is envisaged that the mold of a hearing aid mold can be changed according to the physical structure of the patients at any time. But there is still no related report.

Caposecco *et al*., have developed a set of written instruction materials for self-fitting hearing aids [18], but it is only applicative for BTE hearing aids, and there are no materials for other types of hearing aids. The instructional material adopts a large font and contains a large number of pictures and descriptions, which will inevitably increase page count of the manual. It is obviously that too many pages means a burden for elderly patients with insufficient memory. Therefore, considering the low-cost electronic medium, the author thinks that the most effective instructions should be multi-media presentation instead of caption.

Since the parameters adjustment of self-fitting hearing aids is based on human-machine interaction, it is impractical for patients with hand disability to frequently operate the hearing aid or the control terminal. However, the development of brain-computer interface technology [39-40] may solve such problems. Brain computer interface(BCI) is a direct communication pathway between the brain and an external device. BCIs are often directed at assisting, augmenting, or repairing human cognitive or sensory-motor functions. The field of BCI research and development has since focused primarily on neuroprosthetics applications that aim at restoring damaged hearing, sight and movement. After the electroencephalogram (EEG) signal is amplified and translated into the external command, peripherals can be control by the mind. The structure of hearing aids with brain-computer interface is shown in Figure 5, From the Figure, EEG acquisition module obtains EEG signals in a invasive or non-invasive way through electrodes and EEG amplifier; the signal processing module includes analysis, transformation, classification of the raw EEG, extracting the characteristics that can reflect the intention of the subject, and translate the results into control commands to hearing aids. In this case, a patient can configur a hearing aid in his mind, which will greatly improve the fitting efficiency. Although there are relatively mature products of BCI, its size and power consumption is not suitable for hearing aids. There are still a lot of research works to be done in order to achieve this feature.

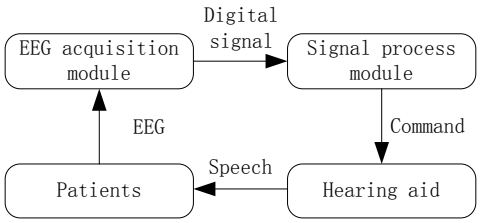


Figure 5. Structure of Hearing Aids with Brain-Computer Interface

4.2. Algorithms of Hearing Aids

Since audiologists are replaced by users for self-fitting hearing aids, large amounts of professional knowledge must be integrated into algorithms of hearing aids. Related algorithms consist of several aspects.

4.2.1. Judgment of Hearing Loss Type: A large number of studies have shown that there is little difference between traditional audiometer and online audiometer [30-41]. However, exact real-time fitting is not possible unless transducer and individual real-ear-

to dail difference(REDD) is correctly proofread and ambient noise is controlled [42]. In general, the initial fitting of traditional fitting is 3-4dB higher than users' preference [43]. However, there are large differences between different patients. The preferable frequency response of patients will change along with the auditory environment. In order to make sure that frequency response conforms to the user's needs, the fine adjustment and training of the hearing aid is necessary. Testing content includes determination of patient's hearing loss type according to results measured by online audiometer. If a patient has difficulty hearing, the first hearing test is very necessary. When the doctor thinks that wearing a hearing aid is appropriate, the patient may select the self-fitting hearing aids. Not all hearing impaired persons need hearing aids, just as not every cardiopath needs bypass surgery.

4.2.2. Parameters Update Strategies: Most parameters of hearing aids are calculated in accordance with fitting formula. Its nature is to obtain the average of configuration parameters based on specific measurements [44-45]. However, due to individual differences, such as age, gender, *etc*., fitting results based on the average are biased [46]. Besides, there are some parameters which are not personalized, such as automated noise reduction speed. Therefore, how to adjust these parameters is a very difficult problem. Difficulties include: 1) The traditional measurement environment is desirable, low-noise, low-echo, and therefore the obtained configuration of the ideal environment differs from that of the actual environment; 2) Results are not optimal even though different environments are simulated [47]; 3) When a patient is exposed to a new sound environment, it is possible that fitting results under different environments are worse than the initial setting; 4) Even though a satisfactory result was achieved through continuous testing, the process inevitably costs a lot of time, which is unrealistic [48]. Therefore, taking into account the increasingly serious problem of aging, developed countries are more inclined to the simplification of hearing aid's fitting.

Automatic adjustment of parameters according to the environment is a new research direction of hearing aids. Currently, the most common method is to use acoustic scene classification algorithms [49]. Although this algorithm has been integrated into hearing aids, the actual effect is not desirable [20]. An effective approach is to determine the current environment by patients themselves, and then artificially adjust the configuration. For example, patients could control variables to achieve the optimal configuration [50-54] according to different environments. Such a method is the same as the design concept of self-fitting, that is, users himself adjust parameters when they are dissatisfied with output of hearing aids due to the change of environment. The difference is that the number and value of parameters of traditional fitting methods are fixed, while self-fitting algorithm is totally dependent on patients' subjective experience. Self-fitting algorithms have more adjustable parameters and the actual effect is better, but it is more complex and difficult to realize. In terms of the self-fitting parameters updating algorithm, Takagi *et. al*., realized parameter optimization of loudness compensation algorithm based on interactive evolutionary computation method [34], while there are no other relevant reports. However, this study provides a feasible idea for self-fitting hearing aids, but there are still many issues that need resolution.

(a) Representation and rank of patient's subjective assessment

Parameters updating of self-fitting hearing aids is mainly dependent on patient's evaluations to sounds. Firstly, the evaluation rank should adapt to patient's separating capacity. In addition, it also includes two contradictory aspects: evaluation burden and bias noise. The more evaluation grade is, the more severe burden of patients is. It will aggravate fatigue, but bias noise is lower.

As for representation of patient's subjective assessment, uncertain numbers such as interval numbers, fuzzy numbers and linguistic values *etc.*, can better meet users'

cognitive rules than determined numbers, which can reduce the burden of users to some extent [55-56]. However, how to use these uncertain number to indicate the fitness value and compare the pros and cons between individuals, and how to extract the appropriate knowledge information to guide the evolution for improvement of performance, are two issues that need be further studied. Because there are many process methods for uncertain numbers in the multi-criteria decision areas, this may be one solution in the future.

In terms of evaluation rank, although subjective tests and statistical tests all show that five or seven discrete values can effectively reduce the burden of patients [57-58], but the rough evaluation will bring much bias noise. Bias noise comes from two aspects. Firstly, because of user's fatigue and cognitive limitation and gradualness, it will lead to the drift and volatility of individual fitness value which will result in cognitive noise and random noise [59]. Secondly, due to the complexity of the problem and the uncertainty of optimization goals, users are difficult to explicate their own preferences and the optimum/most satisfactory goal. With the progress of evaluation, user's original preference will change. When this happens, how to improve the algorithmic optimizing efficiency based on previous evolution and environmental information is challenging. Combining with knowledge base or historical information, establishing an expert system or agent model [60-61] to do an associational evaluation may be an effective method to reduce time-varying bias noise.

(b) Research of algorithm model and convergence

Five or seven discrete values are very rough for algorithms. It will affect the convergence of the algorithm [62], which leads to patients' fatigue, or even failed evaluation. Although Takagi solved parameters optimization problem for loudness compensation algorithm based on IEC algorithm [34], the convergence rate of IEC is relatively slow. Strategies to improve the IEC algorithm mainly include improvement of IEC algorithm's parameters and operators, or appropriate division of the search space, but these are little effect [58-59]. Therefore, research on improved IEC algorithm and new solving model are needed. Improvement strategies contain two ways: 1) New evolutionary models and heuristic algorithms(such as ant colony algorithm, particle swarm optimization algorithm, *etc.*,) are introduced to replace traditional evolutionary algorithms. One design goal is how to maintain population diversity and sufficient optimization capacity in the case of small population size of IEC and low evolutionary generations. Another is group decision-making ability to deal with implicit and explicit optimization problems. 2) Decision models based on prediction of assessment values [60] are established to reduce patient's fatigue and improve algorithm performance. Decision model is determined based on user's preference extracted from individual information evaluated by the user. It can predict the fitness of the individual and expand the algorithmic population size so that to improve the search capability of algorithms. In evolution process, only higher fitness values are provided to users, which can reduce user's fatigue. If a user is tired, the user-agent model may replace the user to evaluate. However, suitable agent model towards uncertain numbers is being studied [61].

(c) Multi-parameter hybrid optimization strategy

With the increasing complexity of hearing aid algorithms, there are more and more parameters need to adjust, such as compression threshold, compression ratio, gain under compression threshold, frequency, noise suppression, frequency shaping, microphone mode, *etc.*, Therefore, the joint optimization of parameters between different algorithms is facing great challenges. Although there is no similar study, parameter optimization of self-fitting hearing aids is the same as multi-source information fusion whose decision-making is implemented with different source data. Therefore, multi-source information fusion theory can be applied to multi-parameter hybrid optimization of self-fitting hearing aids, for example, parameters optimization under the contradictory configurationss can be

realized based on game theory. Such algorithms include game theory based on Bayesian network and decentralized Markov process. However, the application of game fusion needs to be further promoted, and the corresponding model and algorithm also needs to be improved. In addition, with the development of network technology and the explosive growth of information, algorithms of distributed information fusion and multi-modal heterogeneous information fusion can be applied to parameters optimization of self-fitting hearing aids ,even web server [63] and loud computing should be considered.

4.2.3. Design of Expert Knowledge Base: Decision model based on predicted evaluation is an important method to improve the convergence of algorithm and reduce patients' fatigue. In theory, decision model can substitute the experience of experts to adjust parameters of hearing aids. To achieve that, a set of expert knowledge base is established based on findings of psychology and physiology. This base can represent experience of hearing experts through accumulating, learning and reasoning. Figure 6 shows the structure of a expert knowledge base, which includes three kinds of knowledge (general knowledge, evolution knowledge and evaluation knowledge): 1) General knowledge refers to parameters of relatively fixed value, which have the explicit meaning and is usually represented by parameter definition and data range. In self-fitting algorithms, it mainly refers to patients' personal information and audiogram, *etc.*, 2) Evolution knowledge generally is implicit in interactive evolutionary operation which cannot be obtained directly. Such knowledge can be not only solved process information and historical statistics but also the process and extent of patient's preferences; 3) Evaluation knowledge records the mapping relationship between solution space and evaluation information. For these three kinds of knowledge, the expert knowledge base should contain at least three basic operations: sample extraction, knowledge extraction and evolutionary selection. The operation of sample extraction selects samples from evolutionary parameters group. The selection strategy should consider both diversity and evolution of parameters. Knowledge extraction is to associate the data and knowledge information, and gradually reduce the length of parameters to accelerate the convergence in the evolutionary process, and finally obtain satisfactory configure. Evolutionary selection is a very critical operation. It guides the operation of evolution by extracting implicit knowledge reflecting the evolutionary trends, and makes the search area change towards the psychological needs of people as soon as possible. It will reduce evolution generations, accelerates convergence, and ultimately reduce the burden of human evaluation.

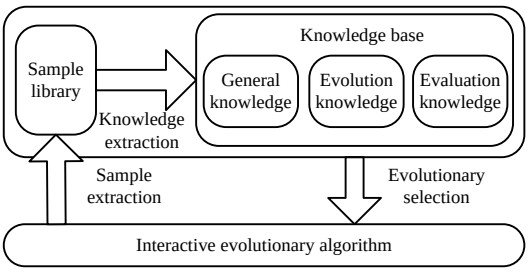


Figure 6. Structure of Expert Knowledge Base

4.3. Cognition and Hearing Aids

One of the advantages of self-fitting hearing aids is that patient's cognitive ability can be integrated into the design of hearing aids. As early as 2003, the MRC Hearing Medical Research Institute of Glasgow Royal Infirmary firstly proposed that individual differences in cognitive ability should be taken into account in the design process of hearing aids [64], and studied the relationship between cognitive ability and compression

characteristics of hearing aids in 2006 [65]. Since then, Linköping University in Sweden and Denmark Eriksholm Hearing Research Center conducted a series of studies. The two institutions analyzed patients' cognitive defects under noisy circumstance [66], discussed the link between signal and cognitive ability [67], and verified the impact of cognition on fitting. In addition, an important opinion is pointed out that the impact of cognition is considered during the design process [68-69]. In Fall Stark Summit 2011, experts on behalf of audiology, cognitive science, psychology, geriatric rehabilitation science had a in-depth discussion around the elderly, cognition and hearing aid technology, and further promoted the development of studies between cognition and hearing aids. In the past decade, studies on cognitive hearing aids mainly focus on three aspects: (1) Cognitive auditory model of hearing aids. Ease of language understanding(ELU) model is a comprehensive model on relation between cognition and auditory function [70], which can assist to achieve the personalized treatment. (2) Impact of cognitive ability on the design of hearing aids. Many studies have shown that listeners with a good cognitive ability, especially those who have large working memory capacity, tend to have better speech comprehension in noisy environment [71]. Hearing intervention techniques combined with cognition ability help to overcome the limitations of current algorithms. Therefore, it is possible to design and adjust some parameters based on cognitive skills [72]. (3) Design to improve the cognitive ability of patients. Hearing loss not only has a negative impact on the auditory function but also affects cognitive function. Successful hearing rehabilitation should restore or improve cognitive function of hearing impaired persons. More and more evidence shows that hearing technology can affect short-term cognitive processing and reduce the cognitive burden of elderly people with hearing impairment, including mental fatigue and reserved selective attention mechanism [69]. Acknowledgment to the contact between cognition and peripheral function shows hearing rehabilitation technology relates to both hearing loss and cognition. These studies make it possible to restore or enhance cognitive function. Therefore, hearing and cognition are closely linked and mutual. In terms of the research on self-fitting hearing aids, cognitive factors should be taken into account while designing materials [18] and testing patients [73]. In addition, how to reflect patients' cognitive ability and how to integrate such feedback into the design of parameters, are still many problems worthy of further study.

5. Conclusions

Self-fitting hearing aid is a bold vision to improve penetration and the quality of the algorithm as well as to enhance patients' satisfaction. Self-fitting hearing aids have high values and bright application prospects, especially in developing countries where lacks of audiologists. Although self-fitting hearing aids have obtained some progress on commercialization and algorithm research, there are still many problems to be solved, especially in parameters optimization and personalization of patients. Therefore, the study for self-fitting hearing aids has great theoretical value, which needs more attention.

However, one thing should be considered that the role of audiologists is essential, even self-fitting hearing aids are very popular. The main role includes:

1) Understand the needs and ideas of users, and help users build confidence. Studies show that patient's motivation is an important determinant for effective usage of hearing aids [44]. In addition, it is very important to help patients balance their mind because patients tend to have too high expectations [21].

2) After the fitting is completed, audiologists can inform patient the announcements, which include the usage of auxiliary equipment, process strategies and methods in complex environments. Besides, it is necessary to help patients establish a correct understanding of speech quality, because some patients do not know how to describe differences of speech quality [48-74].

3) Provide services for future complex hearing devices, such as devices integrated with hearing aids and cochlear implantation [21].

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