Design and Implementation of Memory Assistant Based on Ebbinghaus Forgetting Curve

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Abstract. In view of the single stereotype of memorizing knowledge points with the help of traditional books and easy to distract attention in the process of memorizing with the help of mobile phones and computers, a mobile handheld device, memory assistant, is designed and developed based on Ebbinghaus forgetting law curve, embedded software and hardware development technology, and memory list cycle pushing intelligent algorithm designed by forgetting curve law as the core. The experiment shows that the device is convenient and flexible like electronic devices such as mobile phones and computers, and also has the characteristics of high efficiency and concentration of book memorizing, at the same time, scientific and reasonable learning plan can effectively improve the efficiency of users' recitation and memory.

1. Introduction

Every walk of life and every field of study have its basic and core knowledge points called fundamental knowledge points. They are not only the foundation of the mental activities of human beings, such as thinking and logical reasoning, but also the starting point of our judgement and decision-making[1-2]. However, with the amount of information increasing with each passing day in the era of information explosion, the fundamental knowledge points human beings need to memorize are increasing dramatically[3].

Memorization is the fundamental mode for human beings to acquire new knowledge in quantity[4]. As a matter of fact, we all have to take courses in humanistic and social sciences and natural science such as language and literature, maths, English, history, geography, politics, physics and chemistry in our juvenile years, all of which have a great number of fundamental knowledge points we need to learn by heart. After we have grown up, we have jobs, interests and hobbies, in which a great number of knowledge points appear with each passing day with the progress of the times. To keep pace with the times, we must have a good command of and learn them by heart. Book-based memorizing used to be the major way to keep memory. Now, tools like mobile phones, computers and pad are facilitative to retaining memory. As a matter of fact, book-based memorizing is not only inconvenient but also mechanical. Though memorizing with ordinary electronic devices is a good solution, multimedia such as various games, films and short videos contain entertainment contents, which are nothing but disasters to their users (teenagers in particular) in the memorizing process[5-7].
To solve this problem mentioned in this paper, a memory assistant, a mobile handheld device, is designed, with embedded software and hardware technology, based on Ebbinghaus Forgetting Law Curve\textsuperscript{[8]} concerning the relationship between the human brain and newborn things discovered by Ebbinghaus, a German psychologist. This device is not only convenient and flexible to use like electronic devices, but also enables the user to concentrate on study as book-based memorization. Moreover, based on Ebbinghaus Forgetting Law Curve, an intelligent algorithm is designed which may push list of knowledge point memorizing dynamically in a circular manner, hence effectively enhancing the concentration and memorizing efficiency of the user.

2. Introduction to Memory Assistant Based on Ebbinghaus Forgetting Law Curve

Human memory refers to the processes that are used to memorize, retain, and later reproduce or recognize information. It is the basis of advanced mental activities like thinking and imagination\textsuperscript{[9]}. There are three major processes involved in memory: memorizing, retaining, and recognizing. Memorizing refers to the process of recognizing and remembering external things and form impression while retaining means reinforcing the memory of the recognized contents. Recalling and recognizing refer to two different modes of reproducing the past experience. Retention rate is not only an important indicator to measure the effect of memorizing the external things, but also the precondition for memory and recognition. However, forgetting rate is the deadly foe of memory. As a matter of fact, forgetting rate and retention rate are mutually repulsive. Forgetting rate is used to represent the missing part in the process of memorizing external things in our brain. H. Ebbinghaus, a German psychologist, conducted a research on the forgetting rule of memory. In 1885, he put forward famous Ebbinghaus Forgetting Curve Rule. He discovered that forgetting starts immediately after memorization, that the process of forgetting is not even. According to him, forgetting speed is very fast at first and then becomes lower gradually. Moreover, forgetting rate ($y$) changes with time ($t$), as shown in Formula 1:

\begin{equation}
 y = 1 - 0.56t^{0.06}
\end{equation}

In the formula, $y$ refers to the forgetting rate of the memorized contents and $t$ refers to the change of time.

This project is aimed at overcoming the defects which exist in the traditional book-based mnemonics and the modern mnemonics with the help of mobile phones and computers so as to improve the learning efficiency of the user. A memory assistant, a mobile handheld device used exclusively to assist memory by recitation, is designed, based on Ebbinghaus Forgetting Curve Law, and with the help of the embedded development technology. Moreover, an application software system with intelligent push function is developed, with the device’s embedded operating system as the platform. The sketch map of its work structure is shown in Figure 1:

![Sketch map of the work structure of “memory assistant”](image)

Figure 1. Sketch map of the work structure of “memory assistant”

3. System Design and Implementation

3.1. Embedded Hardware Circuit Design

The memory assistant designed in this project is an embedded system. It takes NXP i.MX 6ULL processor as the core, and its integrated 512M DDR operation memory space and 8G EMMC storage
space constitute the core-board. Apart from the minimum system circuit, it also includes the modules such as pin reuse analog switch SGM3157 (GPIO), WiFi module (UART), capacitive touch screen ATK-7016 (eLCDIF), touch drive circuit module FT5426 (IIC), audio module WM8960, key (GPIO) and 4G communication module EC20 4G(UART). The structure of its major hardwares are shown in Figure 2:

![Diagram](image)

**Figure 2. Hardware Structure Diagram**

WiFi module and 4G Communication module EC20 are mainly used to tackle the problems concerning indoor and outdoor devices networking for the implementation of its information interaction with server-side database. WM8960 is an audio encoding and decoding chip manufactured by Wolfson. It integrates the low power consumption of Class D loudspeaker's power amplifier and the high-quality stereo audio CODEC. Every channel may drive one 1-W loudspeaker. Three stereo input sources are integrated inside for flexible configuration. In addition, it boasts a complete set of microphone interfaces. In this project, it is mainly used to realize Digital to Analog Conversion (DAC) of audio information and guarantee the sound quality and provide the user with interfaces for loudspeakers, earphones and microphones. ATK-7016 is a display which integrates TFT LCD with capacitive touch controller. LCD screen’s interface is eLCDIF, and touch controller’s interface is FT5426. In this project, both are mainly used to realize the interactive function between the graphic display of the device and the touch input of the user. SM3157 is an analogue switch mainly used to solve the problem of LCD and Boot sharing the pin.

### 3.2. System Transplantation

The system requires that specified application program run on the circuit board. As the program cannot run through bare computer program, an operating system needs to be transplanted to the circuit board. The process of system transplantation involves circuit board bootloader transplanting and operating system configuration. In this project, in terms of bootloader, uboot v2019.04_4.19.35_1.1.0 is selected. For operating system nucleus, linux 4.19.35_1.1.0 is selected. For root file system, the file system which builds up Qt 5.12.3 based on Yocto is adopted. Arm-poky-linux-gnueabi is chosen as the compiler. Moreover, u-boot LOGO, Linux LOGO and a start progress bar are added. SDIO WiFi is initialized, and hotspot script and the graphic interface (GUI) are connected as the self-starting-up options of the system. The whole process of system transplantation is divided into two stages: uboot transplanting and operating system transplanting.

The transplanting process of the starting loader uboot chosen in this project is shown as the following:

1) Add altering circuit board configuration files.
2) Add the header file corresponding to the circuit board.
3) Add board-level folder corresponding to the circuit board.
4) Modify Makefile.
5) Modify imximage.cfg.
6) Modify MAINTAINERS.
7) Modify u-boot graphical interfaces configuration files.
8) Compile the modified u-boot.
9) Programming newly compiled u-boot.bin to the SD card with imxdownload.

Operating system transplanting is divided into two parts: Linux kernel transplanting and root file system configuration. Its general steps are shown as the following:
1) Add modifying circuit board configuration files in Linux kernel sound code catalog.
2) Modify Makefile.
3) Add devicetree.dtb corresponding to circuit board.
4) Compile Linux kernel.
5) Compile root file system with Qt 5 through Yocto project.
6) Programming zImage system mirror image, devicetree.dtb, and root file system to EMMC with MFG_Tool.

3.3. System Transplantation
The software architecture of this project is divided into two modules: the server side and the handheld device side. The main functions of the former include data storage, study plan renewal and study plan push, etc. The latter mainly includes some subsidiary functions such as user management, network administration, data transmission, data display and graphic interaction interface design.

The function architecture of the whole system is illustrated as the following:

Figure 3. Software Function Diagram of “Memory assistant”

On the server side, MySQL database is adopted to realize the user’s data manipulation, and data processing is done with Navicat for MySQL. Meanwhile, based on Ebbinghaus Forgetting Curve Rule, an intelligent push algorithm is designed to implement automatic sorting of the user’s study data. In addition, based on the relationship between time lapse and the forgetting rate, a scientific and reasonable review plan for knowledge points is generated. What’s more, the review plan is pushed over the network to the handheld device of the corresponding user, hence implementation of intelligent push function.

The handheld device is the major device which helps to maintain close contact with the user. Its major functions include user registration and login, personal information management (PIM), network connections and management including WiFi and 4G communication and database connection, sending and receiving of various data between the handheld device and the server, information display in the process of using the device, and graphical interface design. Graphical interface design refers mainly to information interactive design between the user and the device. Apart from the implementation of basic information display and user input function, consideration should also be given to other requirements such as visual beauty and the comfortability of the user’s operation in the design process.

4. Algorithm Design for Autonomous Recommendation

4.1. Analysis of the Idea of Autonomous Recommendation
Acquiring new knowledge through the brain is a process of continuous study and forgetting. Newly acquired knowledge points are fresh in memory. However, with the passage of time, the impression of the points in the brain become blurry or are completely forgotten\textsuperscript{[9-10]}. Based on the change rule of forgetting curve, it is clear that at the initial stage, the forgetting rate is the fastest, but later it will become lower and lower. To consolidate the acquired knowledge and enhance memory efficiency, efforts should be made in combining the old knowledge with the new and going over them in the periods of time within the memory cycle in the course of autonomous recommendation algorithm, hence achieving the optimum learning effect. Based on the research results of Ebbinghaus, we may adopt ruminative mnemonics, namely, after the new knowledge is remembered, repeat it in different periods of time: five minutes later, 12 hours later, one day later, two days later, four days later, seven days later, fifteen days later, and 30 days later respectively. In this way, the new knowledge is kept in mind. The memory cycle which lasts 12 hours (including 12 hours) is called short-term memory cycle, and the other cycles are called long-term memory cycles.

Take memorizing English words as an example. Suppose one needs to remember new words in ten days, and he/she needs to remember list n new words per day. According to the memory cycle calculated through the forgetting curve, every new word is reviewed once every morning. Later, it is reviewed every five minutes, thirty minutes and twelve hours according to the periodic law of short-term memory. And then, it is reviewed one day, two days, four days, seven days, fifteen days and thirty days later respectively. In this way, a daily word-memorizing plan may be obtained as shown in Table 1 (for lack of space, only the first-15-day learning plan is shown here):

| Date   | Review the new knowledge points four times the very day (0min-5min-30min-12h) | Review old knowledge 1 | Review old knowledge 2 | Review old knowledge 3 | Review old knowledge 4 |
|--------|--------------------------------------------------------------------------------|-------------------------|-------------------------|-------------------------|-------------------------|
| 1st day| list1 list1 list1 list1                                                       |                         |                         |                         |                         |
| 2nd day| list2 list2 list2 list2                                                       | list1                   |                         |                         |                         |
| 3rd day| list3 list3 list3 list3                                                       | list2                   |                         |                         |                         |
| Fourth day| list4 list4 list4 list4                                                        | list3                   | list1                   |                         |                         |
| 5th day| list5 list5 list5 list5                                                       | list4                   | list2                   |                         |                         |
| 6th day| list6 list6 list6 list6                                                       | list5                   | list3                   |                         |                         |
| 7th day| list7 list7 list7 list7                                                       | list6                   | list4                   |                         |                         |
| 8th day| list8 list8 list8 list8                                                       | list7                   | list5                   | list1                   |                         |
| 9th day| list9 list9 list9 list9                                                       | list8                   | list6                   | list2                   |                         |
| 10th day| list10 list10 list10 list10                                                   | list9                   | list7                   | list3                   |                         |
| 11th day| list10                                                                   | list8                   | list4                   |                         |                         |
| 12th day| list9                                                                     | list5                   |                         |                         |                         |
| 13th day| list10                                                                    | list6                   |                         |                         |                         |
| 14th day|                                                                   | list7                   |                         |                         |                         |
| 15th day|                                                                   | list8                   | list1                   |                         |                         |

4.2. Flowchart of Algorithm Design

The system program is divided into two parts: server-side program and handheld device-side. The user’s acquiring new knowledge is a process of ruminative memory in which the impression in the brain is continuously refreshed. After the user selects a study objective, memory assistant needs to divide the knowledge quantity designed according to the study objective into a N-day learning plan.
The plan is composed of N dynamic learning tasks. Daily learning task means the system automatically and periodically generates the current learning plans for the user based on the acquired knowledge, new learning task and the memory cycle of the brain. That is to say, the current learning schedule is the task list to be dealt with. It is used to store the tasks the user needs to study recently. After continuous N days, the memory task is fulfilled. How to generate periodically the study plan for the user’s future study and push it to him/her based on the acquired knowledge, new tasks to be filled and the memory cycle of the brain is the core of the self-renewed algorithm for learning tasks.

![Flowchart](image)

**Figure 4. Major Processing Algorithm of “Memory Assistant”**

Take memorizing English words as an example. First, add the to-be-memorized words from the Glossary to the corresponding to-do word list L of the user. L includes not only such properties as id, words and word meaning, but also t0 (initial memory time), t1 (previous memory time) and memory times n (0 ≤ n ≤ 10). The initial value of the memory times is 0 which means memorizing does not begin. If the value is 1, it means 5 minutes later (the first memory cycle), memorizing should begin. If the value is 2, it means that 30 minutes later (the second memory cycle) memorizing should be done once again. The rest can be done in the same manner. If the value is 10, it means that 30 days later (the 10th memory cycle) memorizing should be done again. As shown in Figure 4, the server-side program in Algorithm (a) takes out i (the knowledge points) after reading the to-do word list. Then, based on the number of memory times, previous memory time, the current time and the memory cycle, it determines whether the knowledge points need to be put into the corresponding user push list for future use. In algorithm (b), the handheld device side downloads the user push list from the server side to the local disk first, and then takes out the knowledge points in the list one by one for display and to facilitate the user’s memorization. After memorization is completed, add 1 to the number of memory times.
times of the current knowledge points. If the number is larger than 10, it means the knowledge points have been remembered. After the user completes all memory tasks, renew t1 (the previous memory time of all knowledge points), and upload the push list to the server-side, and write back the to-do memory list so as for the server side to generate the push memory list for the next time.

5. Experiment Result and Analysis

5.1. Experiment Conditions
To verify the memory assistant’s effectiveness on memory improvement, in this experiment, 50 rare words are selected as knowledge points. Moreover, 15 students of similar English proficiency from Automation Class one and Class 2 of Grade 2018 of this school are selected as participants. They are divided into three groups based on their learning attitudes: plan-based learners (Group A), active learners (Group B), and casual learners (Group C). The five students from Group A are required to memorize the words according to the study plan of “memory assistant”. The five students from Group B are encouraged with small gifts to memorize the words to the best of their ability in any way they think fit. The five students from Group C may choose their own ways to memorize the words. The memorability of every student in the three groups is recorded on the subsequent 7th day and the 14th day respectively.

5.2. Experiment Conditions
Make track records of the memory results of the fifteen students. The test results of their word memory capacitance on the seventh day and the fourteenth day are shown as the following:

Table 2. Test of Word Memory Capacitance of the Students

| Group               | Student Number | Word memory capacitance in 7 days | Average memorability in 7 days | Word memory capacitance in 14 days | Average memorability in 14 days |
|---------------------|----------------|-----------------------------------|--------------------------------|-----------------------------------|---------------------------------|
| 5 students from     | 1              | 43                                |                                 | 47                                |                                 |
| Group A             |                |                                   |                                 |                                   |                                 |
| (Plan-based learners) | 2              | 42                                |                                 | 45                                |                                 |
|                     | 3              | 41                                | 85.20%                          | 47                                | 93%                             |
|                     | 4              | 47                                |                                 | 48                                |                                 |
|                     | 5              | 40                                |                                 | 46                                |                                 |
| 5 students from     | 6              | 49                                |                                 | 46                                |                                 |
| Group B             |                |                                   |                                 |                                   |                                 |
| (active learners)   | 7              | 44                                |                                 | 40                                |                                 |
|                     | 8              | 46                                | 91.60%                          | 41                                | 84%                             |
|                     | 9              | 47                                |                                 | 42                                |                                 |
|                     | 10             | 43                                |                                 | 40                                |                                 |
| 5 students from     | 11             | 19                                |                                 | 12                                |                                 |
| Group C             |                |                                   |                                 |                                   |                                 |
| (casual learners)   | 12             | 21                                |                                 | 14                                |                                 |
|                     | 13             | 19                                | 38.00%                          | 17                                | 26%                             |
|                     | 14             | 18                                |                                 | 10                                |                                 |
|                     | 15             | 18                                |                                 | 11                                |                                 |

The test data shows that on the 7th day, Group B have the best memory effect, next is Group A, and Group C is the worst. On the 14th day, however, Group A who use memory assistant device boast the best memory effect, the next is Group B, and Group C is still the worst. In the first week, Group B
stay ahead of others in learning efficiency. However, in the second week, Group A come from behind, and Group C still lay behind. After an interview with the participating students, it is understood that the real cause of this phenomenon is that: at the beginning, Group B study with great enthusiasm because of the small gifts. They spend most of their spare time studying. However, one week later, they begin to slack off, as a result of which they have worse performance. Comparatively, Group A are not so active in studying at the beginning. However, “memory assistant” helps them make a scientific and reasonable study plan all the time. Memorizing the words by following the study plan pushed to them, they may achieve the best result within a short period of time. As a result, their performance steadily improves. Group C have the worst performance all the time. For one thing, however they study, they are neither given rewards nor punishment. For another, they lack a scientific and reasonable study plan. They just study as they wish. In addition, seen from the individual data, though the final score of No.6 student in Group B is better than that of No.2 student in Group A, it is understood from the interview that the former works much harder that the latter. It turns out that the former studies in a persistent way. Besides, he spends much time memorizing the knowledge points.

The whole experiment shows that “memory assistant” may automatically work out a scientific and reasonable study and review plan for its user on the basis of memorization goals. It may not only save the user a lot of memory time, but also improve his/her memory effect.

6. Conclusion
In this era of information explosion, a great amount of knowledge needs to be memorized. However, both book-based memorization and memorization with the help of electronic devices have defects. Against this background, in this paper, a “memory assistant” device is designed to overcome the defects, taking the Ebbinghaus Forgetting Curve Rule as its theoretical basis. The experiment results show that on the premise of the same learning tasks, “memory assistant” may improve the memory efficiency of ordinary users. Moreover, it may help to tackle the problems of the user being distracted by various functions of electronic device. It is true that Ebbinghaus Forgetting Curve only reflects the changing relationship between knowledge quantity and the forgetting rate with the passage of time. After all, it reflects the mean value of human beings’ memory rule without considering the fact that users differ from each other in their memory efficiency, habits and features due to their different physiological status, reserve of basic knowledge, learning habits and learning atmosphere. For this reason, they differ in the improvement of their memory efficiency rates.

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References
[1] Xie Shenquan, Analysis of the Properties of Knowledge Points and Their Networks[J]. Journal of Software, 1998(10):3-5.
[2] Sun Chuanzhu, Construction of Micro-lecture Library of Senior High Chinese From the Perspective of Fundamental Knowledge Points[J].Teaching & Administration, 2018(10):57-59.
[3] Meng Weiwei, A New Concept in the Era of Information Explosion—Big Data[J].The Merchandise and Quality,2012(09):9.
[4] Ouyang Shizhong, An Exploration of the Ways to Recite for Middle School Chinese[D].Jiangxi Normal University,2006.
[5] Chen Wu, The Influence of Mobile Phone Use on Teenagers’ Self-control [D].Central China Normal University,2006.
[6] Fu Mingqiu & Xiao Jianing. A Study of the Causes, Hazards and Prevention of Juvenile’s Mobile Phone Addiction [J]. Journal of Chengdu University of Technology (Science & Technology Edition), 2014, 22(02): 74-78.

[7] Wu Meiling, Shen Xiaona, Sun Meiqi, Zheng Lexuan, Liu Yun and Dang Caiping. The Influence of College Students’ Computer Game Addiction on Interpersonal Relationship and Sense of Loneliness [J]. China Journal of Health Psychology, 2013, 21(09): 1432-1434.

[8] Memory: A Contribution to Experimental Psychology, (Germany) written by Hermann Ebbinghaus, and trans-edited by Wag Difei, Beijing Institute of Technology Press, 2013.

[9] Yang Zhiliang, Random Talk on Study of Human Memory [J]. Journal Of Psychological Science, 2011, 34(01): 249-250.

[10] Jaap M. J. Murre, Antonio G. Chessa, Antonio G. Chessa, Martijn eMeeter, Martijn eMeeter. A mathematical model of forgetting and amnesia [J]. Frontiers in Psychology, 2013, 4.

[11] Valentina Di Pasquale, Salvatore Miranda, Raffaele Iannone, Stefano Riemma. Integration of learning and forgetting processes with the SHERPA model [J]. IFAC PapersOnLine, 2016, 49(12).

[12] Che Liping, Researches on Mnemonics: Scientific Memory Methods [D]. East China Normal University, 2004.