A Limb Rehabilitation Training System Based on Augmented Reality and Artificial Intelligence

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***Abstract*—In this paper, a limb rehabilitation system based on the integration of Augmented Reality (AR) and Artificial Intelligence (AI) technology, which is called RAA, is introduced. By creating rehabilitation exercises on a physical system with a crank and pedal mechanism with an AR interface, the RAA enhances the patient's incentive to exercise. Therefore, the efficacy of practice is increased. In addition, the AI platform serves as a medical assistant for patients by suggesting practicing courses according to Fuzzy logic. Furthermore, using the Perceptron network and Microsoft Kinect, the RAA can assess and correct a patient's exercise posture, thereby decreasing reliance on physiotherapists. Training data is stored by the system during exercise, which is a critical parameter for analyzing and assessing recovery. Two experimental processes (*n = 20*) were conducted to assess the efficacy of the RAA, yielding promising results.**

***Index Terms*—stroke, hemiparesis, rehabilitation, augmented reality, artificial intelligence**

I. Introduction

According to the American Stroke Association [1], stroke is the fifth greatest cause of mortality and the leading cause of paralysis in the United States. Post-stroke patients frequently experience total or partial loss of movement. One of them accounts for 80 percent of hemiparesis [2]. During a stroke, the afflicted side of the brain induces paralysis on the opposite side of the body, resulting in muscular weakness here. People with hemiparesis are frequently treated through a multidisciplinary rehabilitation approach demanding physical therapists, rehabilitation therapists, and mental health specialists. However, the current price of therapy is exorbitant. In the United States, the overall cost of stroke in 2008 was estimated at 65.5 billion USD, of which 67% came from costs for doctors, medical professionals, acute and long-term care, medications and other medical durables [3]. The majority of physical therapy is just the repetition of specific motions, and the patient lacks effective interaction with the therapy system. The tedious activity will bore the patient, thus, greatly reducing the effectiveness of therapy. Many studies have oriented rehabilitation to the use of End-Effector Robotic Devices or Exoskeletal Devices to solve this predicament [4]. Although robots have been shown to be beneficial in physical therapy settings, their high cost, poor incentive to practice, and difficulty in home deployment make this therapy challenging. A better motivational strategy is to employ Virtual Reality (VR) technology to create rehabilitation activities in the form of games. A VR system is a computer application capable of generating a 3D environment in which the user is an active participant and interacts with the artificial world using a range of multisensory interfaces [5]. Although promising results have been reported for VR-based advancements [6-7], tracking devices and VR headsets are difficult to sterilize for a large number of patients, and some patients find it difficult or unpleasant to wear such devices [8]. For that reason, AR rehabilitation physical training has been created in order to build a safer and more sustainable environment. AR is a technology that allows computer generated virtual imagery to precisely overlay physical objects in real time, according to a document by Zhou, Duh, and Billinghurst. Visual, auditory, haptic, somatosensory, and olfactory senses are used to carry out these tasks [9]. AR Games for Limb Stroke Rehabilitation is one solution proposed by Burke and colleagues [10]. Users grasping real objects of different shapes and weights in the AR world offers the potential to develop excellent motor skills. A simpler and more cost-effective system was developed by Ying and Aimin [11]. The hardware architecture of the system is uncomplicated, including a PC, a camera and some marked objects, which can be readily purchased in daily life. The patient can interact by operating the marker-affixed objects, then the system utilizes computer vision to perform the registration and tracking of these virtual objects. An AR system, on the other hand, is still too simple, too inflexible, incapable of handling, and making the best decisions for each patient. AI is being considered as a platform for solving this problem. Han and his colleagues used the Convolutional Neural Network algorithm and Beetle Antennae Search algorithm to develop an intelligent recommendation model for cancer patients' rehabilitation [12]. Also, Gal and his team tracked the patient and delivered real-time feedback to maximize the efficiency of the rehabilitation by using the fuzzy inference system with the exercise descriptors [13]. In addition, Jiang researched the rehabilitation for arm muscles using an interactive user interface accommodated with an AI system. The user interface includes programs such as flappy bird and space

Manuscript received November 14, 2021; revised April 11, 2022.

doi: 10.18178/ijmerr.11.6.445-451

shooting in order to offer patients a more interesting and more interactive rehabilitation process while the AI system based on SVM, NN, KNN to make sure they do the correct task [14]. Each rehabilitation method has its own advantages and disadvantages, so to create an effective method, we have studied a rehabilitation exercise system that combines the merits of the ability to collect training parameters of robots, AR's captivating interface, and AI's intelligent monitoring called RAA. This method serves to increase the patient's stimulation to exercise, therefore enhancing exercise results and minimizing rehabilitation therapy costs. With the assistance of AI, the rehabilitation system has become more self-sufficient, decreasing the physical therapist's presence and the medical burden.

Within the scope of this paper, the application of the AR platform to the RAA is presented in Section 2 and the AI platform in Section 3. Part 4 describes the method of determining the efficacy of the system based on two experimental programs in one hospital in Vietnam. Finally, the conclusion is given in section 5.

II. INTEGRATING AR INTO THE SYSTEM

The RAA consists of a mechanical part with a rotating mechanism on which sensors such as a torque sensor, encoder, button, and actuator are mounted to support force when patients show signs of fatigue; a display interacts with the patient as a virtual assistant; and a Kinect sensor is used to collect images of the patient that are data for image processing, as shown in Fig. 1.

The interface is designed on the WPF (Windows Presentation Foundation) platform of Visual Studio with the main colors being light blue and green. AR view, human body model, reality view and Certain user-specific parameters such as leg and arm practice speed, training accuracy, workout support, and practice time are all shown in Fig. 2. AR view is a piece of software. Unity-based script that describes the view of a cyclist on the road. The character in the AR view moves at a speed that corresponds to the user's training rate when the user exercises their arm or leg muscles. Model of the human body showing the major muscle bundles of the body.

Figure 1. Rehabilitation device.

Figure 2. Interface of system rehabilitation practice.

As the user exercises, the device collects data from the sensors and processes and generates outcomes for the muscle bundles being worked, which are represented on the interface by the active muscle bundles changing color to light red. The actual user view is taken from the Kinect sensor display to provide the user with a visual perspective and real-time skeletal analysis visualization. This makes it simple for them to keep track of their progress.

The AR integrated rehabilitation system was created by combining Unity 3D games with a variety of scenery to allow for a high level of engagement between the user and the augmented world. Fig. 3 depicts some of the games we have developed, such as a rowing game to train arm muscles and a cycling game to train leg muscles. Everything in the augmented environment has properties like density, weight, stiffness, momentum, acceleration and many others allowing them to interact physically like in the real world. Patients who utilize rehabilitation equipment will play the part of the game's protagonist in order to achieve some of the exercise goals. The device will capture real-world patient motions using Kinect sensors and sensors installed on the mechanical part of the exercise equipment. From this data, the software evaluates and simulates patient movement. The creation of simulation items in the augmented environment is something we're really interested in. To guarantee that the patient does not have problems adjusting to the new environment, these items must have a reasonably accurate size, location, and shape, and they must interact with one another much like in the actual world. The purpose of this article is to assist patients with performing rehabilitation exercises. As a result, the proposed idea is a 3D cycling game in which players must visit checkpoints to get additional points. We also designed a variety of additional activities, such as rowing and cycling on a variety of terrains, so that patients may fully practice their leg and arm muscles. When the patient's vision changes, the vision in the mini-game needs to change as well. We use the open source face tracking tool provided with the Kinect camera to identify key points on the face. When the patient's head movement was detected, we utilized Unity and an open source package to rotate the camera in the AR environment. The mini games are based on the principle diagram in Fig. 4. Where: V_{arm} is the angular velocity of the top shaft; V_{feet} is the angular velocity of the bottom shaft; P_{h1} is the current vector indicating the patient's direction of sight; P_{h0} is the previous vector indicating the patient's direction of sight.

Figure 3. Several simulated views on screen.

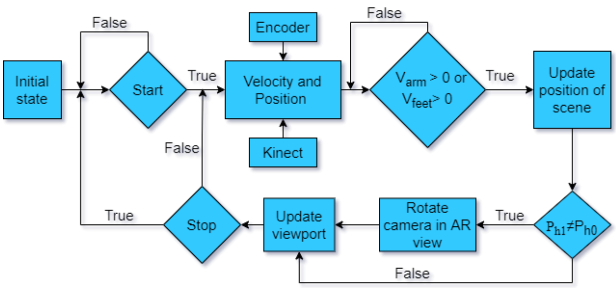

Figure 4. Algorithm flowchart for mini games.

During practice, the number of encoder pulses may easily be calculated to calculate the velocity and direction of the axes. The rotating speed of the training portion of the arms and legs is calculated using these parameters. Then, the patient and doctor can see how the treatment is doing in the interface. In addition, the exercise, the program displays a 3D representation that allows patients to see active muscle bundles in real time. Sensors have been fitted to calculate the torque created by the patient's arms and legs and communicate it back to the computer. The program will display the activity level of the muscle bundles during the patient's workout in real-time based on the torque parameters of the limbs.

Furthermore, a login interface was built to collect data from each patient's practice. These statistics will aid doctors in determining each patient's ability to recover at each stage. The user interface is shown in Fig. 5. The database stores all user data upon logging in as well as metrics during rehabilitative training, such as basic personal information, training duration, and produced torque of upper and lower limb muscle groups. The data will be retrieved so that the patient's rehabilitation capacity may be easily analyzed. We do, however, promise that the patient's personal information will be kept absolutely private.

III. Integrating AI into the System

AI is a significant advancement in science. It represents a significant advancement in the world of medicine. It clearly analyzes information, medical records and systems, and is capable of providing faster and more consistent results. This technology is useful for guiding and managing appropriate treatment for patients [15]. In this study, we used the Fuzzy algorithm to generate a treatment and the Perceptron network to supervise patients during exercise.

A. Treatment

Fuzzy logic theory was developed in the 1960s and is based on the theory of fuzzy sets. In fuzzy sets, the composition of an element is not strictly false or true as in Boolean logic and is not a sharp value, but a gradual value. The membership degree of an element in fuzzy logic can be any real number in the interval [0, 1]. The advantage of fuzzy logic stems from the fact that it allows us to solve the ambiguity and imprecision of many real-world problems. In essence, it simulates human reasoning ability and the ability to make decisions based on not so precise information. Fuzzy logic-based algorithms used in the medical field have shown the potential to improve the performance of doctors by mimicking human thought processes in complex cases and performing key actions. Identify repetitive tasks for which humans are not suitable. As we can see in practice, it is very difficult to accurately determine the patient's health status, so the fuzzy logic can be considered as the perfect solution to handle this situation [16].

Therefore, in this study, we decided to use the fuzzy logic to provide an initial training program from 4 parameters through a survey for patients who are recovering with the RAA for the first time. Accordingly, patients are monitored and indexes on 4 signs are collected through references from the Ministry of Health and experts in the field of physiotherapy in Vietnam, including 4 indexes: age, The Functional Independence Measure (FIM), arm muscle strength and leg muscle strength. FIM is a widely accepted scale used to measure the functional abilities of patients undergoing rehabilitation [17]. Meanwhile, The Manual Muscle Testing Scale (MMT) was used to determine muscle strength [18]. MMT divides muscle strength into six levels, ranging from 0 to 5, with 0 indicating no muscle activation and 5 indicating muscle activation against the examiner's full resistance and full range of motion. In this study, four muscle groups were of interest on the paralyzed side of the patients: Biceps and Forearms, representative of the arm; Quads and Calves, representative of the leg. These parameters are provided by the student after signing up for an account when performing rehabilitation with RAA.

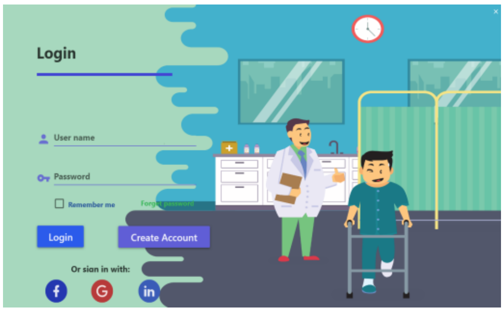

Figure 5. User interface.

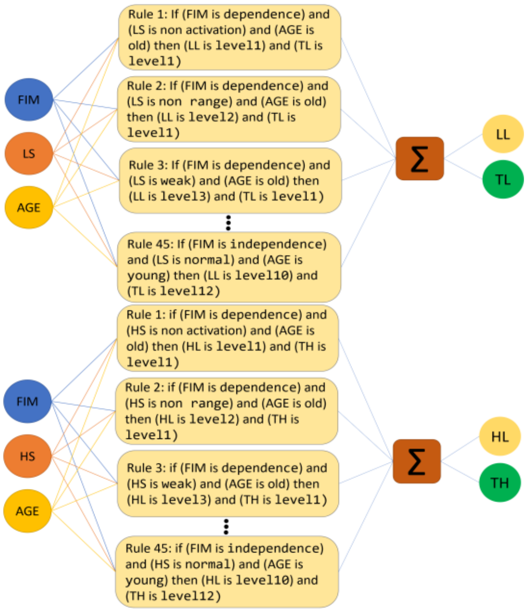

Figure 6. The system model is based on the Fuzzy algorithm.

As illustrated in Fig. 6, the patient's exercise regimen comprises arm practice time, arm practice level, leg practice time, and leg practice level. The resistance on the rotating system of the mechanical portion that the doctor can regulate is referred to as the practice level. These parameters are often the case when the diagnosis may not be very clear. The use of fuzzy logic in this case has shown an effective reasoning method that can deal with uncertainties and ambiguities because it allows for inaccurate representation of knowledge.

According to the guidelines of the Ministry of Health and some physiotherapists, after each exercise day, doctors need to receive patient feedback and give exercises for the next day. Therefore, the system also collects patient feedback, such as pain level after exercise. This degree is measured using the 'Shape Scale', which depicts different faces affected by pain. Patients who are not in discomfort are advised to raise the difficulty of their exercises by 5-10%. The suggested line of action for patients with mild pain is to have them work on the previous exercise. The difficulty level of the exercise will be lowered from 10-30% depending on the amount of pain in the group with severe to very severe pain. The Fuzzy algorithm is used to make all of these adjustments.

B. *Supervise*

One of the system's primary aims is to allow patients to monitor themselves, reducing reliance on doctors and, in general, reducing the health-care system's load. Consider the patient's posture, thereby determining the patient's correct or incorrect posture. Many people after a stroke are paralyzed on one side, so an imbalance in this group of patients is very common.

Therefore, it is necessary to recognize the patient's exercise posture, then compare it with the standard posture and make comments and adjustments accordingly. To recognize the patient's posture, we use Microsoft Kinect, which enables the ability to perceive the position and angle between the patient's joints during exercise [19]. Because the system focuses on analyzing the posture of the upper limbs, lower limbs and back, special joints such as wrists, elbows, shoulder blades, hips, knees and ankles will be recognized. Through the coordinate position of the above joints, the system will calculate the angles between the above positions, giving a set of instantaneous parameters according to the patient's training time. This parameter set is compared with the pre-generated standard parameter through the Perceptron network. The Perceptron is a classification algorithm for the simplest case: only two classes and also only works in a very specific case. The inputs here will be the angles between the patient's joints. The Perceptron network will calculate these values according to the weights they have learned through the standard pose angle values. From there, the Perceptron checks the correctness of the patient's position and relies on that. When it detects that the perceptron has a deviation from the standard parameter, the system will calculate the deviation, thereby correcting the exercise posture by notifying the patient, for example, to raise or lower the elbow.

IV. EXPERIMENTS AND DISCUSSIONS

A. *Participants*

Twenty volunteers with hemiparesis who were being treated at a hospital in Vietnam took part in the experimental process to evaluate the RAA. To ensure that the volunteers understood the doctor's instructions during the experiment, they had to pass a consciousness test (Glasgow index ≥ 13 points [20]). The average age of patients is 50.3 (range from 35 to 63 years) and the average day post-stroke is 85.3 (range from 38 to 156 days). Male patients made up 55% and right hemiparesis accounts for 60% of the total number of volunteers.

Figure 7. The patients are participating in the experiment.

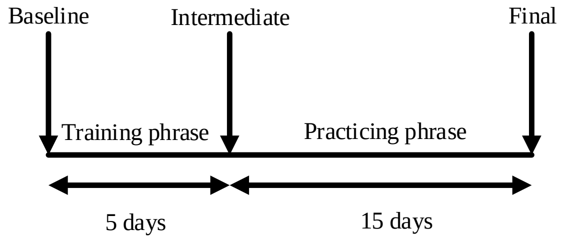

Figure 8. The timeline of the study.

B. *Protocol*

Because of the hospital's small size, the experiment was repeated twice (for the first time: No 1-10 and the second time: No 11-20). Both experiments lasted the same amount of time and used the same method. Each experiment was divided into 2 phases with the timeline shown in Fig. 8. The patients are assessed three times (Baseline, Intermediate, and Final), using two scales: MMT and The Satisfaction scale (Sas). The overall MMT score is determined by the average of 4 muscles: Biceps, Forearms, Quads and Calves. Meanwhile, Sas is rated on a scale of 1 to 5: 1-extremely dissatisfied; 2-dissatisfied; 3-average; 4-satisfied; 5-extremely satisfied.

The patients were split into two groups: Both groups practiced on the same physical equipment, but group B exercised with the assistance of AR and AI (using the RAA). During the training phase, each patient received one 10-minute training session per day on the procedure and how to exercise on the device. After 5 days of training, they went into 15 days of practice with one session per day. Group A practiced with time and level under the guidance of a doctor, while group B exercised with the course that was prescribed by AI. Both experimental procedures were carried out with the hospital's permission and the consent of all patients.

C. *Data Analysis*

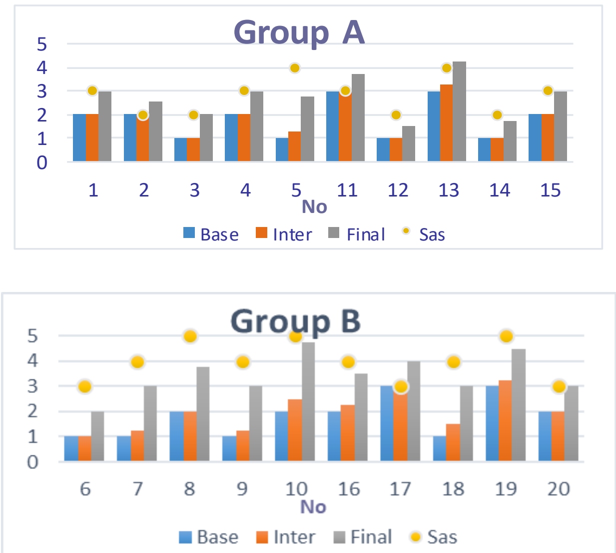

Figure 9. Evaluation results of the training.

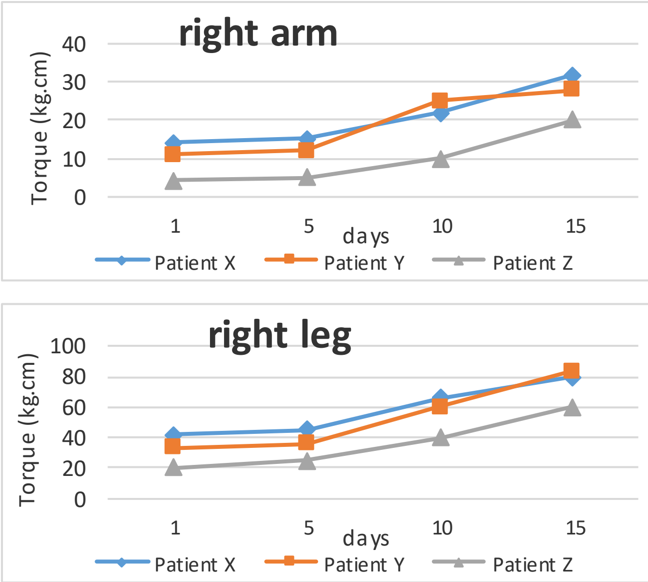

Figure 10. The average torque of 3 patients.

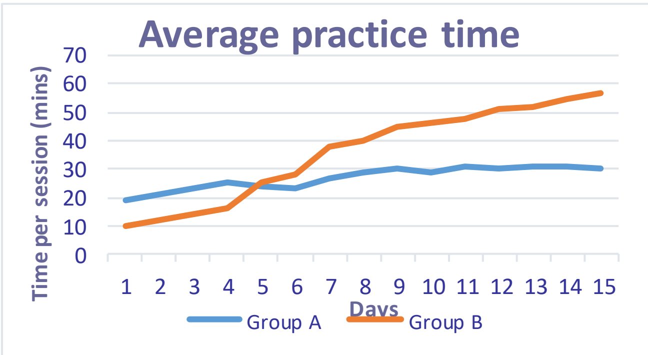

Figure 11. Time spent exercising by two groups.

We can see a common trend in the experimental results displayed in Fig. 9: while both groups showed improvement in muscle strength, group B expressed a more positive signal. Statistics show the average results of Base and Final in group A are (1.8, 2.75) and in group B respectively (1.8, 3.45). Apparently, group B showed a greater improvement in the patient's muscle strength (1.65 vs 0.95). Not only in terms of health but also the patient's training spirit was significantly improved with the Sas index consistently high (average of 4-satisfied) and no patient complained about rehabilitation on RAA (Sas < 3). Meanwhile, in the remaining group, the patients felt just normal (the mean Sas index was 2.8). More specifically, patients No 2, 3, 12, and 14 have been dissatisfied with traditional rehabilitation exercises due to limited improvement in results. To get a better look, we randomly selected 3 patients with right hemiparesis in group B called X, Y and Z. Fig. 10 shows the average torque data generated by paralyzed arms and legs on days 1st, 5th, 10th, and 15th of the practicing phrase. One trend appears to be that torque increases slowly in the first few days, until around the fifth day, when it begins to show a significant increase. At this point, the histogram is a straight line with a high and irregular slope between the patients. This can be explained by the fact that RAA is still relatively new to patients, so access is difficult in the early stages, but once they get used to it, the speed of recovery is quite impressive.

Although the doctor in group A and the AI in group B recommend exercise time, the exercise will be finished if the patient shows signs of exhaustion or signals to stop exercising during the practice. Because the final practice time is entirely dependent on the patient's decision, it's also meaningful in assessing the patient's motivation to exercise. Fig. 11 depicts the average daily exercise time of the two groups of patients in the practicing phrase. Group A practiced for about 27 minutes per session. They entered better (19 minutes per session) perhaps because they have long been familiar with traditional practice methods. However, the practice time increased quite limited. The main reason for this sluggish change is that traditional equipment and monotonous exercises repeated every day make patients feel bored and lack motivation to practice. In the meantime, the data for patients who belong to group B is more optimistic. Because the patients were unfamiliar with AI technology and the AR environment in the beginning, the exercise period was comparatively short (just about 10 minutes), and the quality of training was somewhat limited. But after about 4 days, the patients seemed to adapt to the system relatively well, they were more interested in the new technology, resulting in increased training time each day. At the end of the test, their practice time reached an impressive number, 57 minutes per session.

V. Conclusions

In this paper, RAA assists patients with rehabilitation exercises will help patients perform rehabilitation exercises through real-time interactive mini-games between the user and the system. This increases their motivation to exercise and allows them to interact with the AR environment, where they can participate in sports activities even if their health does not allow them to do so in the real world. The RAA also provides workout regimen recommendations thanks to its AI-based app. This combination solves the problem of less efficiency and simplicity in traditional training methods. Therefore, this system is evaluated by patients as making them more comfortable, achieving high efficiency, and thereby reducing rehabilitation training time. Patients can perform their own low-cost rehabilitation activities at home without requiring the assistance of a medical doctor. However, their exercise is still monitored by the system and notified to the doctor when necessary. This helps reduce the overload of patients and physical therapy facilities at medical facilities. In the future, the authors still have a lot of work to do to optimize the system. The first is to increase the accuracy and ability to monitor patients. Next are augmented virtual games that provide richness. Finally, make a lot of judgments and analysis to come up with the optimal treatment for each patient based on the parameters during exercise for maximum effectiveness in each exercise.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Nguyen Truong Thinh, Nguyen Anh Quoc conducted the research; Tran The Luc, Nguyen Vo Tam Toan analyzed the data; Nguyen Truong Thinh, Nguyen Anh Quoc, Tran The Luc wrote the paper.

Acknowledgment

The authors wish to thank the volunteers who are recovering from strokes, as well as the therapists at Thu Duc General Hospital, for taking the time to provide advice and feedback to the author team. We would also like to thank the Ho Chi Minh City University of Technology and Education in Vietnam for providing financial support and study facilities.

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