An Interactive Robotic Walker for Assisting Elderly Mobility in Senior Care Unit

Kuan-Ting Yu[†], Chi-Pang Lam[‡], Ming-Fang Chang[‡], Wei-Hao Mou[†]
Shi-Huan Tseng[†], and Li-Chen Fu[†‡], *Fellow, IEEE*
[†]Department of Computer Science & Information Engineering, National Taiwan University
[‡]Department of Electrical Engineering, National Taiwan University

***Abstract*—This paper describes a robotic walker, Johnnie, that provides assistance to mobility-challenged people, especially elderly people. Our walker is modified from a conventional unpowered four-wheel walker by equipping motors, sensors and some safety devices, providing mobility and stability to it. In our software system, we provide two modes: (1) autonomous mode in which the walker can autonomously navigate to the user without collision, and (2) rehabilitation mode in which the walker will assist the elderly to walk safely and smoothly. We have done a preliminary test of the two modes in our lab environment and analyzed the result.**

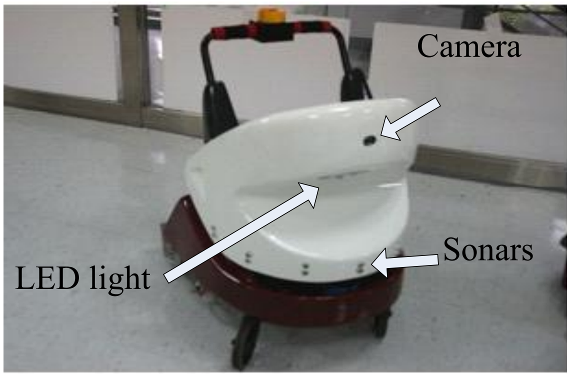

Fig. 1. View of the robotic walker we designed.

I. Introduction

Recent studies have shown that the elderly population is growing at a dramatic rate [12] such that the demand for elder care increases rapidly. At the same time, one of the most frequent problems among the aged is walking. The elder lacks not only sufficient physical support for himself, but also a safe environment to walk. Paths might be uneven or full of obstacles. These problems usually cause the elders to fall down and seriously injured. However, locomotion is most often the primary form of exercise that maintains the elder's health status. In order to deal with the shortage of human assistance as well as the hidden risk in the everyday environment, robotic walking aids were thus created.

Overall, our robotic walker provides two modes: (1) autonomous mode in which the walker can autonomously navigate to the user without collision, and (2) rehabilitation mode in which the walker will assist the user to walk safely and smoothly. The system incorporates several innovations from us and also inherits some features from the previous work. The overall hardware and software can be depicted as Fig 2. and Fig 3. We have done a preliminary test of the major functions in our lab environment in order to see if the walker is suitable for the elderly.

II. Related work

Robotic walking aids have been studied extensively throughout the past decade. According to the propulsion of the robot, we can divide them into two categories, namely passive and active. A walker is passive means that it relies on user's pushes to move, whereas an active walker possesses motorized wheels to move by itself. Passive robotic walkers like [1] [2] [5] [6], gives the user full control of the robot movement. The passive robot tends to be much simpler in design and therefore lighter and thinner. Wasson *et al.* [6] addresses that instead of doing too much for the user, the walking aids should only affect the user at the presence of danger. However, when dealing with slopes, it might be unsuitable because the user not only have to exert more force on an up-going slope, but also have the chance of being pulled forward on a declining slope. On the other hand, active walkers such as [3] are propelled by its motors that keep its speed in control. Therefore, the active walker is comparatively more suitable on slopes, that is, it is much safer. In addition, an active walker can perform navigation function, in which the robot can automatically drive to the designated place, i.e. user's location, without collision [3]. In sum, the active walker surpasses the passive one in both safety and walking convenience, but is much more complicated in system design. On the other hand, hybrid system also exists, where user can switch between the two styles [13].

In the aspect of medical functionality, investigators at Massachusetts Institute of Technology designed the Smart Walker, which can monitor user's health status such as heart rate in case of emergency or for diagnostic purpose [1] [2].

In this paper, we further enhance the active robot's ability with several innovations. First, the *step-by-step* technology enables the robot to keep the same speed with the user all the time by tracking the user's footsteps. Second, the foot tracker can keep records of each footstep, which provides doctors with crucial evidence of the patient's walking ability. Finally, we incorporate an online music player on the walker for entertaining purpose. Although none of the previous work mentions any entertaining function, however, it has been

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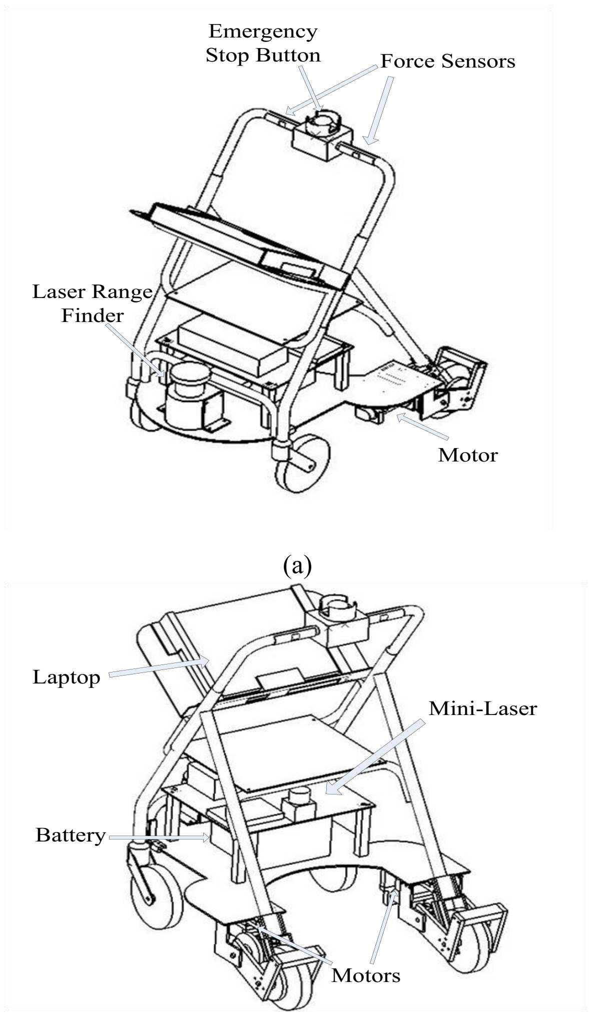
proven that appropriate music has positive influence on elder's with certain disorders such as anxiety [10].

III. System Overview

A. Physical System Overview



(b)

Fig. 2 (a) the front side (b) the rear side of our walker

Figure 1 shows the appearance of our assistance walker. Based on the conventional four-wheel walker, we equip two motors, an emergency button and four major sensors on the walker, as shown in Figs. 1 and 2. First, four force sensors are covered on the two handles. If the user exerts more force on the left handle, the walker will turn left, and vice versa. Second, 7 sonar sensors are embedded around the lower body of the walker. Sonar can detect objects in the range of 500 cm. Third, a laser range finder is equipped at the lower front in order to perform localization and mapping. Fourth, another mini-laser is equipped at the lower back to track user's footsteps. Powered motors are equipped on the rear wheels to provide mobility. For safety concern, there is an emergency stop button on the top of the walker. Pressing this button will lock the motor so that the walker will stop immediately. Moreover, a LED light is mounted on the front of the walker in order to provide illumination so that it is still usable in dark surroundings.

B. Software System Overview

There are two computers on the walker: (1) an industrial PC, setting on the bottom, respond to control motors and collect information from sensors, and (2) a tablet PC used as touch user interface. When user wants to use the walker, paramedics or user should turn the industrial PC on by pressing the physical switch on the case of the walker. Then, start it up by using the simple interface. After start-up, there are two modes in the system. One is autonomous mode, and the other is rehabilitation mode. Users can click on the touch screen to switch between them. When user wants to stop using the walker, he can turn off the whole system by pressing the button on the touch interface, but the tablet PC can be optionally kept running so that the entertaining function will be still available. The full system flowchart is shown in Fig. 3.

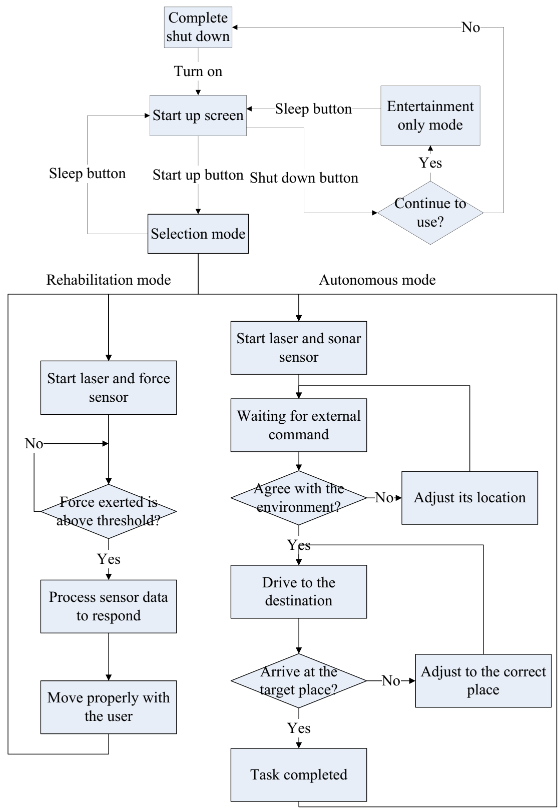


Fig. 3. System flowchart.

IV. Functionality

A. Autonomous mode

Asking the elders to find the walker is inappropriate. Therefore, we design the autonomous mode, in which the user can simply click on the remote to order the walker to proceed to the user's location without collision. In order to achieve this function, our system has three main components: localization, path planning, and obstacle avoidance.

1) Localization

Before achieving the localization task, the walker needs the map of the environment. Using the front laser range finder, we apply the grid-based simultaneous localization and mapping algorithm [8] to get the map of the working environment. Monte-Carlo localization is adopted here. The equation below describes how localization is done:

$$\hat{x}_t = \arg\max_{x_t} \{P(z_t \mid x_t, M^{t-1}) \cdot P(x_t \mid \hat{x}_{t-1}, u_t)\} \qquad (1)$$

In equation (1), $P(z_t \mid x_t, M^{t-1})$ is the measurement model, which stands for the probability that measurement z_t is observed, given pose x_t and the constructed map M^{t-1}; $P(x_t \mid \hat{x}_{t-1}, u_t)$ represents the motion model, which is the probability that the robot is at x_t given previous pose $\hat{x}_{t-1}$ and control u_t.

2) Path Planning

The walker exploits a standard A* algorithm to find out a shortest path, as shown in Fig. 11. The map used in path planning has been dilated with the size of our walker so that even the path in the black region in Fig. 11, it is still an acceptable path for robotic walker.

3) Obstacle Avoidance

Our navigation system is implemented with "Nearness Diagram (ND) Navigation" [9], one of the most popular reactive methods. It works well even in complex environment. Since most indoor settings are dense and complicated, we adopt ND navigation to handle such environment in real time.

4) Come-to-me Function

With the ability of localization, path planning and obstacle avoidance, we can achieve the "come-to-me" function. First, as shown in Fig.4, users first define some common positions in their environment, for example, the entry of the elder's room, the side of the sofa, etc. Then send orders via voice or via a remote like a Bluetooth or Wi-fi device. Afterwards, the walker will navigate to the designated position.

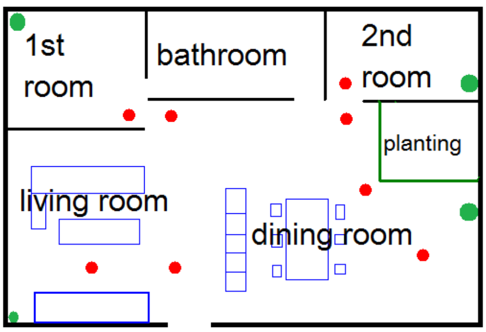


Fig.4 Dots are defined points for "come-to-me" function

B. Rehabilitation mode

As the user wants to begin walking, he will first switch the walker into rehabilitation mode by clicking on the screen. Then, he will stand straight and hold the handles. The user can control the direction by gripping more firmly on the corresponding handle.

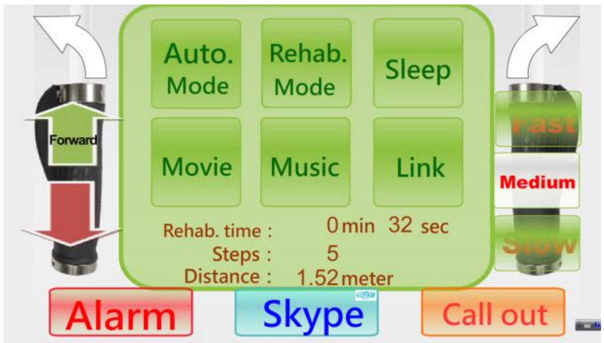


Fig. 5. Touch user interface in rehabilitation mode. On the right, user can set the walking speed to fast, medium or slow. On the left, user can choose either to walk forward or backward. On the bottom, buttons from left to right allow user to sound the alarm, make a skype call and call the care center. In the middle, the three captions from top to down show the elapsed time, total steps and the total distance. The buttons and captions are large enough for elders to choose.

1) Safety state

In order to prevent walker from collision in rehabilitation mode, walker will actively maintain its safety via the front laser range finder. As shown in Fig. 6, we detect the obstacle within the angle β. If there is obstacle closer than D_{safe}, the safety distance, the walker will enter an unsafe state. In this state, walker cannot go forward anymore, but user can control the walker to rotate via the haptic handles to escape from an unsafe state.

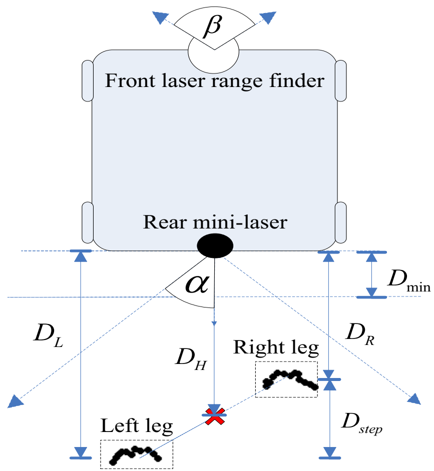


Fig. 6. Detection of human legs

2) Step-by-step

In order to determine human legs, we divide the rear laser data into left part and right part. We only concern the data where the angle is between $\pm\alpha$ from the center angle of the mini-laser and in the distance between 100mm to 1000mm. As shown in Fig. 6, D_R is the average distance between right leg and the walker:

$$D_R = \frac{1}{M_R}\sum_i d_i \cos\theta_i$$

where d_i is an available right laser data (angle between α and distance between 100~1000mm), θ_i is the corresponding angle to d_i, M_R is the number of available laser data. Similarly, the average distance between left leg and walker is:

$$D_L = \frac{1}{M_L}\sum_i d_i \cos\theta_i$$

Trivially, the estimated distance to human is:

$$D_H = 1/2(D_R + D_L)$$

and the estimated gait distance is:

$$D_{step} = abs(D_R - D_L)$$

The criteria for walker to move forward are:
(i) The walker is safe and in forward mode
(ii) Both two legs are detected
(iii) $D_H - 1.5D_{step} < D_{\min}$ should be satisfied, where $D_{\min}$ is the minimum distance maintained between human and the walker, and $D_H - 1.5D_{step}$ is the estimation of the position of next step. Note that $D_H - 1.5D_{step} > D_{\min}$ means that there is still enough space for the user to make the next step so that walker does not need to move forward.

Therefore, the walker only proceeds as the user steps forward. This is to deal with the unstableness of the elder's footstep. Since the distance moved by the walker is determined by the step size and position of the user, an appropriate distance between the user and the walker will be kept. Otherwise, if the user holds its step, the walker will be braked tightly. This prevents the user from accidentally sliding forward by putting too much weight on the handle.

User can also set the speed to fast, medium or slow according to the actual need. If the walker gets into a narrow space (e.g. in the elevator), in which turning around is impossible, user can switch to backward mode by clicking on the touch screen in order to move back.

Meanwhile, if the user carelessly gets too close to these objects (i.e. lesser than 30 cm. in our configuration), the walker will be braked hard to avoid collision. On the other hand, the step size and the time for each step will be recorded. The record is an important reference for the doctor. The record format is shown in Fig. 7.

Footstep#	Accumulated distance	Current step size	Time(Y_M_D_H_M_S)
1	0.01421	0.01421	2010_8_17_17_23_30
2	0.02132	0.00710	2010_8_17_17_23_31
3	0.03553	0.01421	2010_8_17_17_23_32

Fig. 7. Format of the footstep record.

C. *Entertaining Function*

In order to motivate the elders to rehabilitate themselves with the walker and reduce the boredom of the exercise, we develop an online music player in the walker. Users can listen to music by clicking on the touch screen. The song lists including YouTube links for each song can be updated through internet. Then, the music videos will be acquired from YouTube. The interface is shown in Fig. 8.

Fig. 8. Online music player.

V. RESULTS

In this section, we evaluate the function of Rehabilitation Mode and Autonomous Mode of the walker; the walker is proved to be stable, safe to use, and capable of autonomous tasks such as obstacle avoidance and path-planning.

A. *Rehabilitation Mode*

In this experiment, we invited 5 users and each user can operate the walker with the highest speed for 3 minutes. Besides, no other constraints are given. The walker is proved to be safe even in the highest speed mode.

1) *Safety evaluation*

When the walker starts, it will impose a force on the user. Let F represent the force, m_h represent the human mass, and v_w represent the velocity of the walker. The kinematic energy of the force exerted on the user is

$$K = \frac{1}{2} m_h v_w^2 = F \times step\ distance$$

In practice, $m_h \cong 80$kg and step distance = 0.3m. The exponential relationship between F and v_w is shown in Fig. 9. If the speed is set too high, the force from the walker's handle can be so large that human would fall easily, which is a very dangerous for the elders. After several trails, we heuristically set the maximum walker linear speed to 230 mm/s and the max angular speed to 50 m/s, with maximum F only about 0.7kg. These parameters are proved to be acceptable by the questionnaire responses.

The velocity and angular velocity of one of the users are recorded in Fig.10(a). We can see vibration caused by user's step.

Finally, the distance between the user and the walker are shown in Fig.10(b). When the walker is moving, the shortest distance from the walker to the user is in the range of 50-200mm, which is considered comfortable for the users.

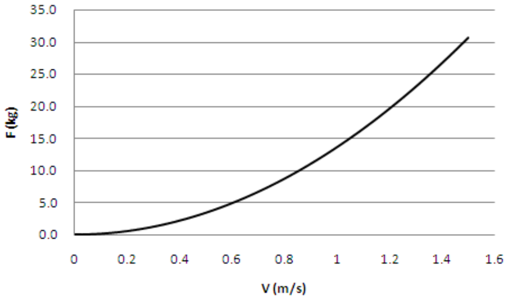
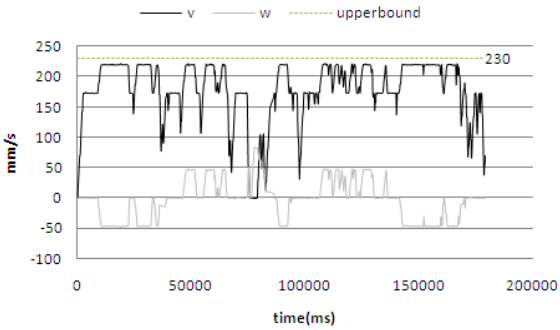


Fig. 9. The relationship between force and velocity

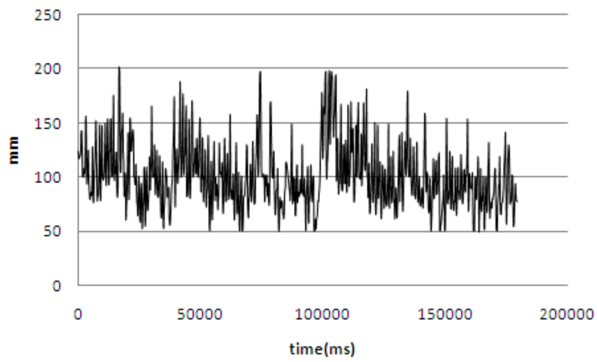
2) *Questionnaire*

In order to reflect the user's feeling of the walker, we have designed a 5-point questionnaire. After using the walker, each user is given this form to provide their feedback. The results are shown in Table 1.

Most of the items got neutral score, which shows that the performance of the walker is acceptable and can still be improved.



(a)



(b)

Fig. 10. (a) The velocity and angular velocity of the walker with upperbound = 230mm/s. (b)The minimum distance between user and the walker.

TABLE 1

THE QUESTIONNAIRE AND THE RESULTS

Mobility and control		**Score**
Inconvenient	convenient	3
uncomfortable	comfortable	3
Incontrollable	controllable	3.25
User interface		
not user-friendly	user-friendly	3.25
boring	amusing	3.5
Others		
bad appearance	Good appearance	3
Total Evaluation		
dislike	like	3.5
*5 signifies very positive and 1 very negative		

B. *Autonomous Mode Result*

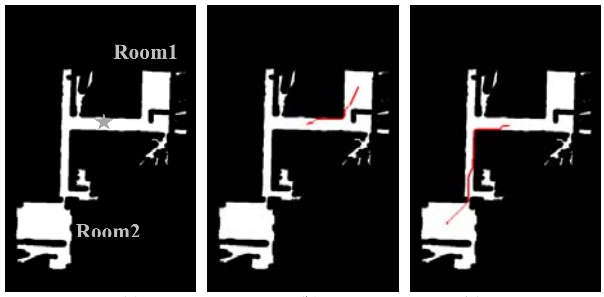
1) *Obstacle Avoidance*

This experiment tests if the walker can move autonomously in a care unit such as Fig.12(a). We simulate the environment in the laboratory like Fig.12(b). During this experiment, the walker keeps moderate distance from other objects with maximum velocity of 250m/s.

Notice that we simulate human feet in care unit with two sticks in our lab environment.

2) *Come-to-me*

This experiment examines if the walker can navigate to the user's location on receiving a command. We set targets in each room on the map. As the result, the walker can follow the path to the target room without any collision.



(a) (b) (c)

Fig. 11. (a) shows the dilated map of 2F in Min-Da Building in National Taiwan University. There are two rooms in the environment, and we use a star to mark the walker's location. (b) and (c) shows the path of the walker when it is called by people in Room1 and Room2.

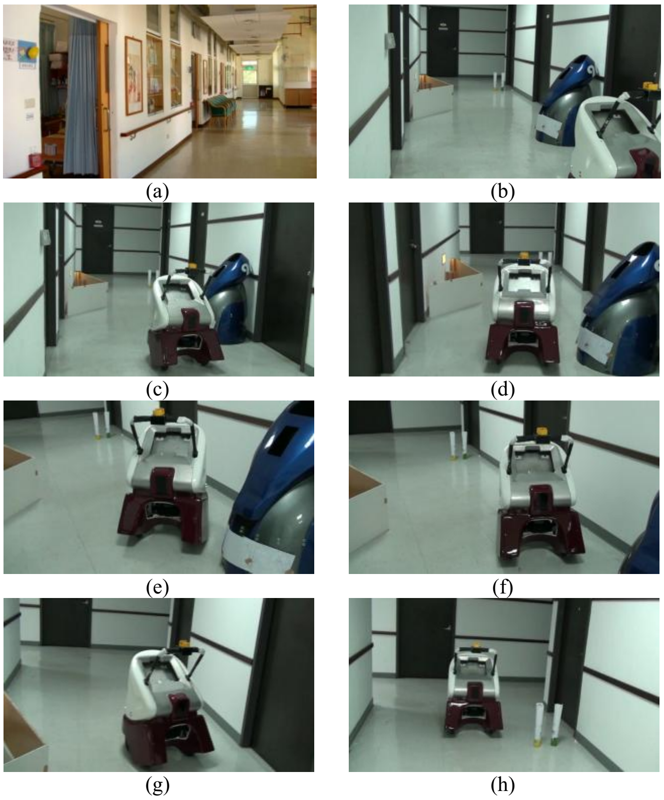


Fig. 12. The obstacle avoidance behavior of the walker in autonomous mode. (a) photo of a typical care unit. (b) shows our lab environment with simulating obstacles. (c)-(h) shows the behavior of the walker, routing successfully around the obstacles.

Further experiments will be done in real care units. There we will receive the data from the elders for more practical evaluation.

VI. Conclusion

In this research, we have designed the walker, an active robot, which can not only help the elders walk safely but also navigate to the user's location autonomously. A preliminary test for safety has been done on the walker and we have received acceptable user response by questionnaire. In the future, we will keep on improving the walker's performance based on user's response. Further experiment will be done in a real senior care unit.

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