Study on a Practical Robotic Follower to Support Home Oxygen Therapy Patients

-Questionnaire-Based Concept Evaluation by the Patients-

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***Abstract*—Home oxygen therapy (HOT) is a medical treatment for the patients suffering from severe lung diseases. Although walking outdoors is recommended for the patients to maintain physical strength, the patients always have to carry a portable oxygen supplier which is not sufficiently light weight for this purpose. Our ultimate goal is to develop a mobile robot to carry an oxygen tank and follow a patient in an urban outdoor environment. We have proposed a mobile robot with a tether interface to detect the relative position of the foregoing patient. In this paper, we report the questionnaire-based evaluation about the two developed prototypes by the HOT patients. We conduct maneuvering experiments, and then obtained questionnaire-based evaluations from the 20 patients. The results show that the basic following performance is sufficient and the pulling force of the tether is sufficiently small for the patients. Moreover, the patients prefer the small-sized prototype for compactness and light weight to the middle-sized prototype which can carry larger payload. We also obtained detailed requests to improve the robots. Finally the results show the general concept of the robot is favorably received by the patients.**

I. INTRODUCTION

Home oxygen therapy (HOT) is a physician-prescribed treatment for patients suffering from severe lung diseases such as Chronic Obstructive Pulmonary Disease (COPD). Breathing supplemental oxygen through the nose via cannula increases the amount of oxygen in the blood, usually reducing shortness of breath and other symptoms, allowing more independent life and increasing survival. By introducing an oxygen concentrator, HOT can maintain the quality of life of the patients because they can live in their home. There are many pieces of home medical equipment and services providers and HOT is fully covered by health insurance in Japan. It is reported that over 150,000 people get HOT treatment in Japan [1].

An appropriate exercise, such as a walk, is recommended for COPD patients to keep physical strength. Figure 1 shows a commonly used portable equipment for going out. However the total weight of the equipment is not sufficiently lightweight for the patients: they are over $4kg$ including a carrier cart. Carrying a heavy cart may stress the lungs and becomes a physical and psychological burden. Consequently, there are many patients who do not want to go out frequently.

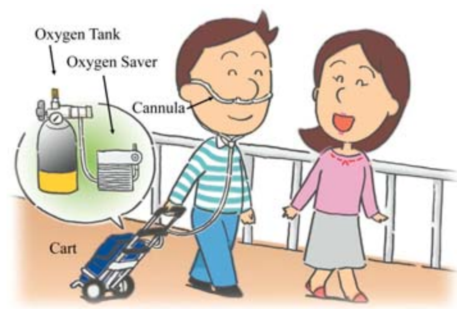

Fig. 1. Portable oxygen supplier

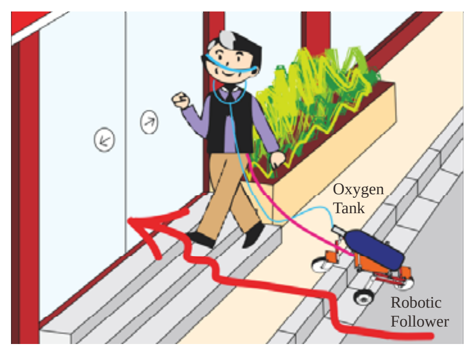

Fig. 2. Basic concept of the robotic follower carrying an oxygen tank

In this study, our ultimate goal is to develop a mobile robot to carry an oxygen tank and follow a foregoing person in an outdoor environment (Fig. 2). For a more concrete use case, we assume that "the patient goes out shopping to the nearest grocery (convenience) store". Because the main purpose of going out (except for regular hospital visits) is shopping in daily life. Moreover, we emphasize low cost production as much as possible, because most of the HOT patients are pensioners [2].

The robotic follower, named by [3], which is a mobile robot following a foregoing person, is not a novel idea because many previous works can be found in the literature such as [4]-[7]. However these previous works used multiple expensive wireless sensors and their applications were limited to an indoor environment.

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Therefore in our previous work, we proposed to utilize a tether to detect the relative position of the foregoing person to be robust and cost-effective, and developed new mobile platforms capable of carrying an oxygen tank in an outdoor environment.

We believe that the questionnaire-based evaluation and direct comments through trial use by the patients are extremely important in order to develop a practical assistive device. It is also important to review the initial specifications and assumptions of use case based on the feedback from the patients. Otherwise the development of this robot may fall into self-satisfaction of robotics researchers.

In this paper, we report the results of questionnaire-based evaluation of the basic concept by the HOT patients. We demonstrated our robotic followers in front of the 20 HOT patients, and then the patients used the robots. After their trial use, we did questionnaire-based investigation about these robots.

II. Prototype Models of Robotic Follower

We can do questionnaire-based survey without making a prototype model at the initial stage of concept design. However we believe that we should make a prototype model beforehand when we do questionnaire-based survey. Because the questionnaire response may be ambiguous if we use a new concept and technology which are beyond patient's imagination.

Therefore we developed prototype models at first, then we demonstrated them in front of the patients to convey solid image of our design concept. After the demonstration, we did the questionnaire survey to get concrete feedback. In order to get concrete response about specifications such as the size of the robot, maximum payload and so on, we developed two prototype models with different specifications.

As for the common features of two prototypes, we use two drive wheels to control the propulsive velocity and direction of the robot. This configuration is one of the simplest mobile base which satisfies both high reliability and low production cost. In the front part of the robot, there is a reel on a turning table as a tether interface which can measure the length and direction of the tether. Since one extremity of the tether is attached to the waist of the foregoing patient and the tether is always tensioned by very weak force not to slack, the robot can detect the relative position of the foregoing patient. Note that the patient pulls the tether but tether is used for only measurement, and the robot follows the patient by controlling the velocity of the active wheels, not by the pulling force.

Of course we can select wireless sensors to detect the relative position of the foregoing patient. However wireless sensors tend to be expensive and not sufficiently robust in an outdoor environment. Moreover oxygen supplier is inherently tethered system. Thus there is no need to use wireless sensors. This tether sensing device is significantly cost-effective and robust compared with a laser range finder and stereo vision camera.

In the following section, we describe overviews of the two developed prototypes.

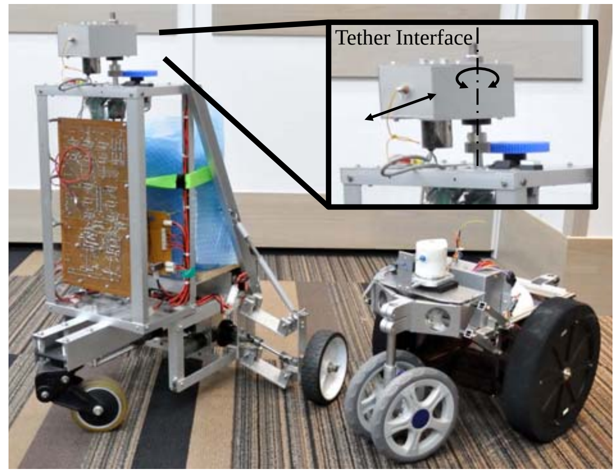

Fig. 3. Prototype Models: middle-sized model(left), small-sized model(right)

TABLE I. Specification of the prototypes

	Middle-sized Model	Small-sized Model
Size L x W x H *mm*	480x650x710	670x330x350
Mass *kg*	11.3	7.5
Maximum Velocity *m/s*	1.2	1.0
Maximum Step Height *mm*	30	90
Operation Time *min*	150	60
Payload *kg*	10	2.5

A. Middle-sized Prototype Model

Although the total weight of an oxygen tank and additional equipments is around 2.5kg, many patients may want to carry other personal belongings and/or purchased goods. Therefore we developed a middle-sized robot which has large luggage space and relatively high payload. Figure 3(left) shows overview of the robot and Table II-A(left) shows its specifications.

A passive casters with elastic base is installed in the front part of the robot, and two active wheels suspended by parallel links and springs are equipped in the rear part of the robot. Moving velocity and direction are controlled by differential angular velocity control of the active wheels. As for the following control, we have proposed three following methods: pseudo-joystick steering control, follow-the-leader control and modified follow-the-leader control [11]. This middle-sized robot uses pseudo-joystick steering control which is the most direct implementation of a following controller. The length and direction of the tether is regarded as the magnitude of translational velocity and direction of the velocity, respectively. Thus, the robot always tries to generate moving velocity to the current tether-end position.

We have reported the following trajectory of the robot, usability evaluation by normal subjects and long distant following experiment using this middle-sized robot [8].

B. Small-sized Prototype Model

The most frequent request to improve the present oxygen supplier is to reduce the total weight and size[2]. Thus the patients may request a small lightweight mobile robot whose luggage size and maximum payload are rather limited. Additionally, it is very important for practical mobile robot to negotiate various steps in an urban outdoor environment. Thus we developed the small-sized compact prototype model that can negotiate a step of 80mm based on the chassis mechanism of a planetary exploration rover[9]. This prototype model has sufficient ability to negotiate a step which usually separates a street and a side walk in Japan. Figure 3(right) shows overview of the robot and Table II-A(right) shows its specifications.

The small-sized prototype model has a four-wheeled rhomboid shape configuration where the front and rear wheels are passive casters, and the middle right-and-left wheels are active wheels. The front passive caster is connected by the two inclined parallel linkage to the middle wheels in order to equalize the distribution of the ground vertical reaction forces on each wheels when the robot negotiates a step. This mechanism can also minimize the required maximum driving torque to negotiate a step. In order to maximize the luggage space of the robot, we designed a special low-profile in-wheel motor with a large diameter. The tether mechanism, which has basically the same functions of the middle-sized prototype, is also improved to be compact and lightweight. We implemented two following algorithm, pseudo-joystick steering control and modified follow-the-leader control, and a user can select the control mode.

We confirmed that this small-sized prototype, carrying the equivalent payload of the oxygen equipment, could negotiate a step of 80mm, which is almost 2 times higher than that of a normal chassis mechanism [10]. We also verified that this prototype could follow a narrow winding trajectory by using modified follow-the-leader control [11].

III. Questionnaire-Based Evaluation

A. Method

We conducted a questionnaire-based evaluation through full coordination with “A Meeting for the Pulmonary Rehabilitation Studies in Hokushin” and its derivative “Hokushin Flying Disc Club”. “A meeting for the pulmonary rehabilitation studies in Hokushin” established in 2004 is organized by medical doctors, nurses, nutritionists, pharmacists and other medical stakeholders whose affiliations are six major hospitals, seventeen clinics and sixteen home-visit nursing stations in Northern Nagano prefecture (Hokushin). “Hokushin Flying Disc Club” is a volunteer group consisting of respiratory patients and medical staffs, and organizes flying disc games as a part of comprehensive respiratory rehabilitation program which is carried out by “A Meeting for the Pulmonary Rehabilitation Studies in Hokushin”. The club members enjoy flying disc games once a month in the same place, and there are medical doctors and nurses with sufficient number of oxygen suppliers to ensure the medical safety. We made a questionnaire survey during the flying disc games.

At first, we introduced our robots and the purpose of this investigation, then we got an informed consent form from each participants. Next, we asked the patient, who was willing to maneuver the robot, to walk straight for a round-trip of 20 meters, holding the extremity of the tether. One of the authors as an experimenter always walked behind the patient in case of unexpected robot movement and/or the patient’s falling. The experimenter also carried the oxygen tank instead of the patient due to the safety reason and time limitation for the experiment. Figure 4 shows an overview of the experiment. We did not discriminate the middle-sized robot and the small-sized robot because there was no clear difference of the following capability when the patient walked relatively slow on the flat ground. The duration of the maneuvering experiment for each subjects was 1-3 minutes on average. After the experiment, we asked the patients to fill in a questionnaire form.

Fig. 4. Following experiment by patients

B. Results

In this section, we discuss the results of the questionnaire-based evaluation. We obtained 20 responses in total (male: 15, female: 5). The average age of the patients is 74.4 years old. The number of the patients who maneuvered the robot is 14, which is 70% of the total participants. We asked the patients to fill in the form to the extent that the patient could, considering the physical and time limitation. Therefore non-response was not directly related to a negative judgment, but because the patient did not have sufficient time to fill in all questions and/or did not pay enough attention to the questionnaire form. Thus we discuss the results focusing on the rate of the valid responses.

1) Evaluation of the Basic Performance: Figure 5 shows the evaluation results of the basic performance of the robot such as velocity, braking ability and steering ability for following. Next were the questions: Q1:Was the robot able to follow you accurately in sufficient speed?, Q2: Was the robot

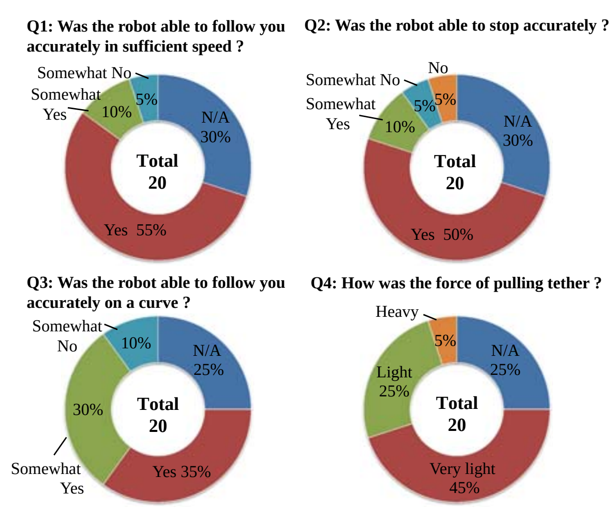

Fig. 5. Questions and answers about basic performance of the robot

able to stop accurately? and Q3: Was the robot able to follow you accurately on a curve? The results suggest that the robots have sufficient following capability because the valid responses are almost positive. (However Fig. 5 also suggests that the steering capability should be improved because it has less positive responses compared with other abilities.) Then, we ask Q4 about the pulling force of the tether, and most of the patients' answer is light, suggesting that the tether does not become a physical burden of the patient. These results imply that the robot has sufficient following abilities without applying a physical load to the patient.

In order to acquire concrete requests to improve the robots, we compared the middle-sized prototype and the small-sized prototype. We asked "Q5: Do you think which robot is convenient for you?" showing the difference between two prototypes about the total weight of the robot, the operation time, the maximum payload and the maximum step height on the questionnaire form. As a result, 67% patients prefer to the small-sized robot whereas only 9% patients choose the middle-sized robot, suggesting that the strong requirement of compactness rather than payload capacity.

We asked concrete improvement on the robot to obtain detailed needs of the patients. Figure 6 shows the results where multiple responses allowed. The results indicate the order of the priority of improvements are longer operation time, quick charging, lightweight, negotiating higher step and payload weight and size. "Getting on train/bus/car" and "going up continuous steps" have relatively lower priority, which is technically very difficult to achieve by a low cost mechanism.

2) Evaluation of the Basic Concept: Unfortunately, the HOT patient has to always carry the oxygen supplier whenever he/she goes out for the rest of his/her life because pulmonary disease, represented as COPD, never cures even in modern medicine. Moreover the HOT patient is always "tethered" at home because the cannula is connected to an oxygen concentrator via a long oxygen tube, preventing the patient from a free indoor walking. Our initial motivation to develop this robot is that the free empty-handed walking seems to be very valuable for the HOT patient compared with a healthy person even in the limited time. Therefore we asked "Q7: Do you think it is valuable to be able to walk empty-handed?".

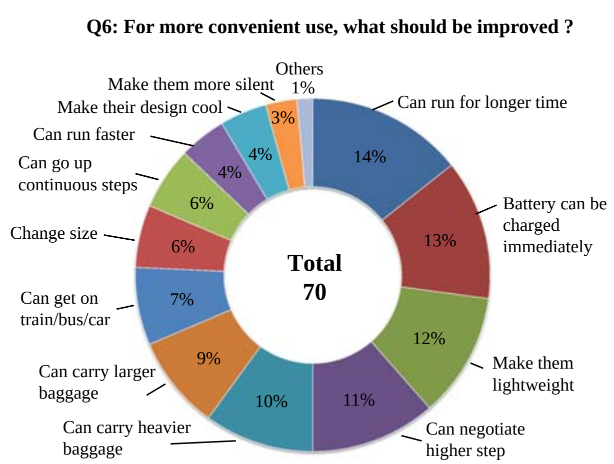

Fig. 6. Concrete improvement requests (multiple answers allowed)

The result is shown in Fig. 7(left). Almost all patients answer positive response, and this result suggests our proposed robot is advantageous compared with the current portable oxygen carrier where the patient always has to use one hand to pull the cart.

The final question is that "Q8: would you like to use this kind of robot?" The result is shown in Fig. 7(right). The number of positive responses is more than twice the number of negative responses, suggesting that our proposed robot is relatively better received by the patients. Additionally, we asked the patients that how much money can you personally afford for this robot. The averaged answer is 797 USD, which is close to the initial cost assumption by the authors.

IV. DISCUSSION

This section considers the results of questionnaire-based evaluation in detail. First of all, there are many positive responses about this research in general. However it is not proper for the authors to directly accept these positive responses.

While most of the patients had been dissatisfied with the conventional portable oxygen supplier and carrier for many years due to the heavy weight and handling difficulty, we proposed to the patients an automatic robotic follower as a brand new solution which might satisfy their longstanding hope.

Moreover, the authors explained that the aim of this research was to reduce the physical burden of the patients. Therefore, there is a possibility that the patients' answers could be positively biased. We should keep these facts in our mind, and discuss the major results.

As for moving speed, braking and steering performance, many patients were satisfied with the basic abilities. However we did the experiments in a large and flat space without any obstacles. For the development of a practical robotic follower, we need to test the robot in the real outdoor environments with obstacles, curbs, bumps and so on. As for the comparison between the middle-sized prototype and the small-sized prototype, the patients chose the small-sized prototype. The result seems that the patient can not feel the advantage of the middle-sized prototype even if it can carry large payload, because the current cart is already too heavy and bulky [2].

As for the request of concrete improvements, operation time is recognized as a issue of higher priority. At the beginning of this research, we set the basic specifications of the robotic follower to accompany a patient to the nearest

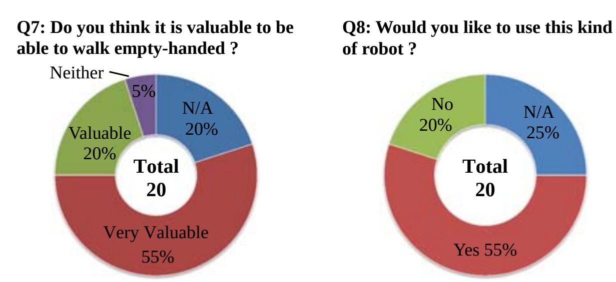

Fig. 7. Questionnaires and answers about overall concept

grocery (convenience) store. However Northern Nagano, the experimentation site, is a rural area where people heavily depend on automobile as a major means of transportation. Thus, they once go out, they stay outside much longer time than we estimated in an urban environment. Actually averaged time when the patients once go out is 2.5 hours, and our prototype does not satisfy this operation time. Moreover, the patients who participated in the experiment and questionnaire survey, may have a great deal of curiosity and their daily activity level may be relatively higher.

As for the terrain adaptive abilities, the patients recognized less priority. We only showed a movie of a small-sized robot negotiated a step and did not ask the patients to experiment on this. We believe that the terrain adaptive abilities are crucial functions for practical mobile robots. It is very important to collect more data regarding terrain adaptation in patients' real-life settings. There might be many steps and bumps which the patient does not recognize but are critical to the robot.

As for the general concept of the proposed robot, we confirmed that the patients found the robot useful for their empty-handed walking. We also received many requests from the patients to use this robot everyday. These requests really encourage the authors to further proceed this research.

By the way, we have to consider the relative location of the robot to the patient. The present method allows the robot to walk behind human. It is relatively easy because the robot can measure and record the trajectory of the foregoing patient to some extent. The trajectory of the foregoing patient becomes the future trajectory of the following robot. Thus, the robot knows its future trajectory in advance. However the patient may feel uneasy about not knowing whether the control of the following robot is perfect, because the robot is always outside the patient's eyesight. In fact, some patients requested during the experiment that the robot should be in the patient's eyesight. If the control algorithm enable the robot to walk alongside the patient, the patient may feel easiness. However it is very difficult to go through a crowded street because the robot occupies the larger space in width. If the control algorithm keeps the robot ahead of the patient, the occupied width can stay narrow. However it requires additional sensors and algorithm to estimate the moving direction and velocity of the patient because there is no leader to be followed. We plan to investigate the aforementioned algorithms. We believe that mode changes in accordance with the environment may be effective for the actual application.

Finally, the authors would like to report an unexpected, but delightful episode. We announced this experiment by distributing handbills to the patients visiting out-patient clinics for their regular check-ups. Initially, the authors were concerned that sufficient number of patients may not participate. However, our experimentation turned out to be an attractive event for the patients, and the number of participants doubled from the previous regular patient meeting. Some patients were simply interested in the word "robot". One patient said "it is my pleasure to join this experiment to contribute to the future development of a useful device." The authors learned that this kind of experiments and evaluations could also offer an opportunity of social inclusion for the patients. According to the survey, 90% of the participants are willing to join the next experiment.

V. Conclusion

In this paper, we reported the questionnaire-based evaluation about the practical robotic followers to assist HOT patients to go out and walk with portable oxygen supplier. We conducted the maneuvering experiments by using two prototypes, and then obtained data by questionnaire from 20 patients. The results show that the basic following performance is sufficient and the pulling force of the tether is sufficiently small for the patients. Moreover, the patients prefer the small-sized prototype for its compactness and lightweight to the middle-sized prototype which can carry large payload. We also obtained detailed requests from the users to improve the robots. Finally, the survey results shows that the general concept of the robot is favorably received by the patients. The authors believe that it is very important to make an continuous effort for evaluation and improvement until the robots meet practicality requirements in real-life environments. We do hope to contribute to the HOT patients' better quality of life.

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