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Low cost sensor network for obstacle avoidance in share-controlled smart wheelchairs under daily scenarios

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ABSTRACT

Intelligent wheelchairs working in various environments need to sense the neighborhood around itself and prevent dangerous situation such as collision and falling down from stairs. In this paper, we develop a low cost and real time intelligent wheelchair shared control system for people with disabilities at the rehabilitation center or at home. Our system is composed of an electric wheelchair, an RGB camera, an infrared camera, 4 ultrasonic sensors, a laser LiDAR (light detection and ranging equipment), and a personal computer. Based on the intelligent sensor network and sensor priority control algorithms, it can detect different obstacles with various dangerous levels, send out voice and graphical alarm, and suggest a safe path to avoid them. The combination usage of the RGB camera and the IR camera enables our system to work under normal lighting conditions and under low lighting conditions. The reliability of individual type of sensors and the whole system was examined by simulated scenarios and user questionnaire. Experiment results reveal that the system is reliable and effective. The key components in our system are low cost and easy to be installed on various electric wheelchairs and common PCs. It will be a useful tool for further developing smart wheelchairs with shared control frameworks.

1. Introduction

Electrical wheelchairs are one of the most popular assistant tools for enhancing the quality of the elderly and disabled people's life. The wheelchair is electrically powered and is commonly used to provide mobility and to improve the independence for handicapped people. However, conventional electrical wheelchairs, which are usually just operated by a joystick, are not always suitable to meet the need. Many disabled people find it necessary to provide auxiliary assistance to drive the wheelchair, for example, the obstacle avoidance assistance technique. Further, intelligent wheelchairs with sensors and automatic auxiliary assistance algorithms would require less attention from the users to drive [1–7]. Therefore, it can be meaningful to the application which combines the wheelchair and the brain-computer interface (BCI) that usually consumes much attention of the user [2,5,6,8–12]. Also, in BCI wheelchairs, the less commands that the user is needed to send, the less fatigue that the user may suffer [5,10].

Currently, advanced sensor technology and mobile computing make it possible to build an intelligent wheelchair. Researches focused on intelligent wheelchairs have already received significant attentions. While some researchers have focused on improving the autonomous function of the wheelchairs' mobility [3,4,11,13], others focused on sharing the mobile control with the user [2,8,10]. Shared control frameworks take both advantage of computer assistance and users' intelligence, which can help the wheelchair driver in dangerous situations, extending the capabilities for handicapped people. Shared controlled paradigms are also easy to cooperate with many other control paradigms like brain computer interfaces and virtual/mixed realities, especially, the shared control of wheelchairs can help to reduce the attention mental resources. Otherwise, the users need to continuously pay attention to the brain computer interface and are easy to be fatigue [5,10].

To implement shared control paradigm, several requirements should be fulfilled. Obstacle avoidance should be operated in real time to fit in real world dynamic environments. Thus, many researches took low computational consuming algorithms into action [6,14]. Daily scenarios should be considered since the beginning of design. Overall user safety, usability and comfortability are critical [6]. Low cost and easy installation to existing wheelchair can also help more handicapped people benefiting from the intelligent wheelchair [15]. There have been a number of studies reporting various designs to fulfill requirements above. RGB/RGB-D cameras, laser range finder (or LiDAR), 3D laser scanners, ultrasonic sensors and accelerometers were successfully used in many projects separately or in different combinations [3,16–19].

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Sonars and RGB cameras have been introduced for decades. Other passive vision technologies like stereo RGB cameras have also been used for human detection and movement tracking. Action vision like laser scanners have also proved their usability, especially in artificial intelligent autopilot vehicles [20,21]. Each kind of sensors and cameras has its pros and cons, thus there were a lot of combination of such equipment to better perceive the condition of the environment.

For daily usage, there are still some problems to be addressed: (1) Obstacle avoidance in low light condition is common; (2) High development cost; (3) Difficult to extend and adapt in flexible usage scenarios; (4) The complexity in algorithm computation. These problems are difficult to be compromised. Therefore, we propose a practical real-time shared control paradigm based on low cost sensor network to provide obstacle avoidance for electrical wheelchairs. In the implement of our system, an RGB camera, an infrared (IR) camera, 4 ultrasonic sensors and a laser LiDAR (light detection and ranging equipment) were used to form a sensor network which were robust enough to ensure the users' safety without optimal amount of information under low light conditions. The proposed approach has the advantage of the efficiency of obstacle avoidance and fall protection, as well as the affordability of total cost. The reliability of the proposed sensor network was examined and tested by simulated scenarios.

2. Methods and materials

2.1. System architecture

The intelligent sensor network is composed of an RGB camera, an IR camera, a LiDAR and 4 ultrasonic sensors. The cameras and the LiDAR were installed at the right front of an electrical wheelchair. If the user need to change the installing location, any other places with the similar height without blocking out the LiDAR's laser emission should be suitable. Four ultrasonic sensors were installed at the lower frontend of the wheelchair. Two of the sensors were facing forward to collect obstacle information at the forward direction, the other sensors were facing downward to prevent falling (Fig. 1).

Table 1
Infrared and RGB color camera properties.

Parameter	IR Camera	RGB Camera
Max resolution	640 × 480	1920 × 1080
Ratio	4:3	16:9
Vertical field of view	55° ± 2°	41.5° ± 2°
Horizontal field of view	71.5° ± 2°	68° ± 2°
Diagonal field of view	88° ± 3°	75.2° ± 4°

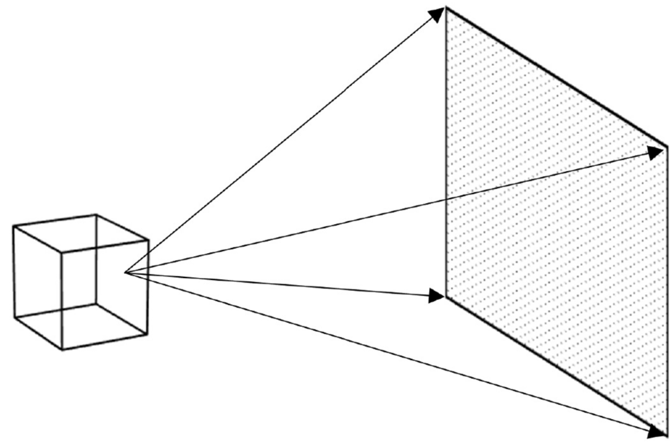

Fig. 2. Camera field of view.

2.2. Cameras

In our implementation, we used an Intel RealSense SR300 device to provide both the infrared (IR) camera and the RGB color camera functionality. The IR camera was used to get the infrared image frame (under low light conditions) and the depth data stream, and the RGB camera was used to get light field frame (under normal light

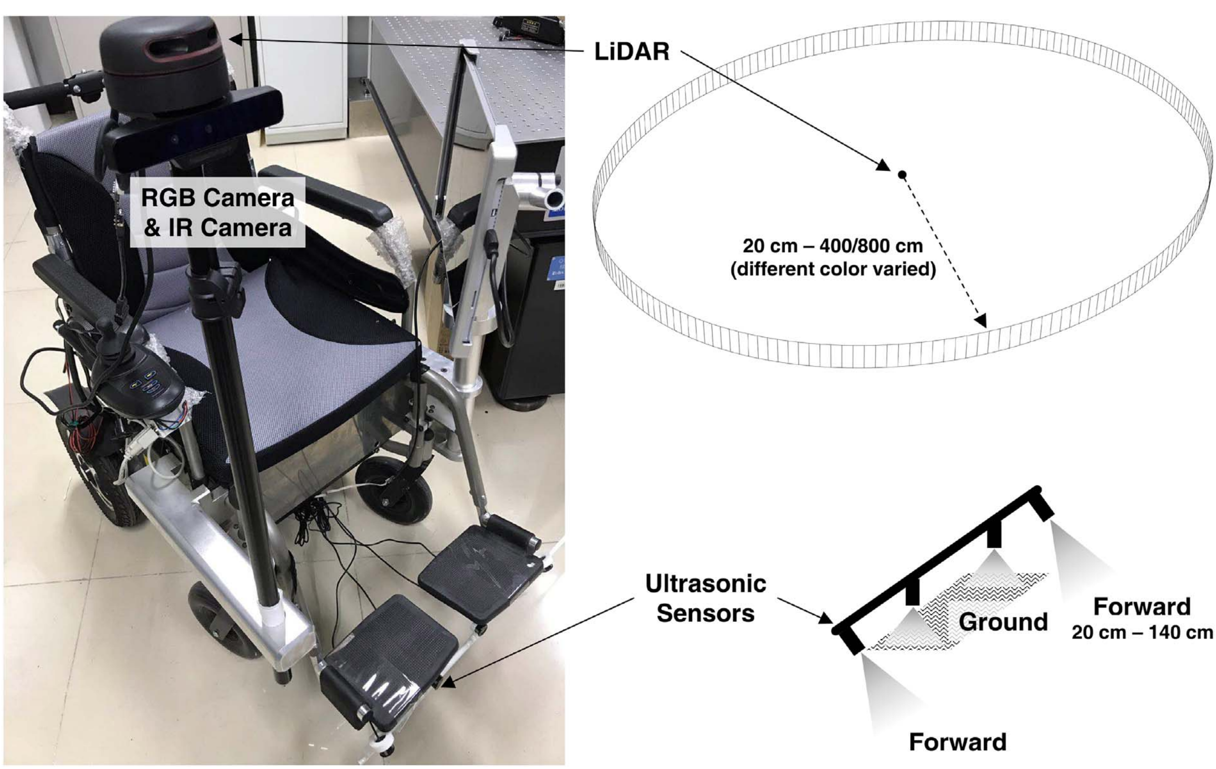

Fig. 1. System architecture and sensors placement.