Study of Fall Detection Using Intelligent Cane Based on Sensor Fusion

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Abstract:

A three-wheeled omni-directional cane robot is designed for aiding the elderly walking. A new human fall detection method is proposed based on fusing sensory information from a vision system and a laser ranger finder (LRF). This method plays an important role in the fall-prevention for the cane robot. The human fall model is represented in a 2D space, where the distance between the head and the average leg position is a significant feature to detect the fall. The possibility distribution of this distance is estimated by using Dubois possibility theory. Fall detection is implemented by using a simple rule based on the possibility distribution. The proposed method is confirmed through experiments.

1. INTRODUCTION

Many countries have entered the aging society very rapidly. Elders suffer from physical and cognitive degradation, such as poor eyesight, lack of muscle strength and so on. In addition, the growing elderly population causes the shortage of people for nursing care. Hence it is significant to design intelligent robots assisting the elders in daily life. Walker-type support systems are important ones among them because the ability of walk is one of the most fundamental functions for humans.

So far, many researchers have developed various intelligent walkers comprising active or passive wheels and supporting frame. Kotani et al. proposed the Hitomi system to help the blind in outdoor environment [1]. Fujie et al. developed a power-assisted walker for physical support during walking [2]. The Care-O-bot and Nursebot are developed as personal service robots for elderly and disables [3, 4]. Yu et al. proposed the Personal Aid for Mobility and Monitoring (PAMM) system to provide mobility assistance and user health status monitoring [5]. Hirata et al proposed a new intelligent walker based on passive robotics to assist the elderly, handicapped people and the blind [6].

There are still many deficiencies in the present walker systems. First, many walkers are designed for the indoor environment. Second, most of them are big in size and/or heavy in weight. An indoor robot is often restricted within limited places. Big size makes it impossible to be used in narrow space and heavy weight restricts the maneuverability. Many elders and patients are not so weak that they have to be nursed carefully. Nevertheless, sufficient support, like a cane or stick, is necessary to help them take a walk outside, which enables them to realize high-quality lives or accelerate the rehabilitation. In these cases, an intelligent cane system may be more useful than walkers due to its flexibility and handiness. In [5], a SmartCane system is also proposed, which has relative smaller size and nonholonomic constraint in kinematics. The nonholonomic constraint is useful for moving along a path stably, but reduces the maneuverability of the system. In the living environment including the narrow space, the cane system is expected to be movable in omni-directions. Thus, omni-directional mobile platform is needed in the robot design. This kind of platform has been considered in some applications [7, 8]. Whereas, their designs are special and not commercially available. Particularly, they are proposed for walker systems but cane systems, which are much smaller in size. Recently, commercial omni-wheels are applied in the area of walker systems [9]. The problem that slender rollers of omni-wheels have limited load capacities is partly solved by the modern technology. In addition, small omni-directional platform can be constructed by this kind of wheels.

In our previous study, an intelligent cane system was designed based on a commercially available three-wheeled omni-directional platform [10]. A hierarchical control scheme was proposed with estimation algorithm for human intentional moving direction. Because falling down of the user is the most serious problem for using the walker or cane system, we investigate the fall detection function of these systems in this study. In [11], Hirata utilized the distance between the user and RT Walker as a feature to distinguish between the walking state and the emergency state. This distance was measured by a laser range finder (LRF)

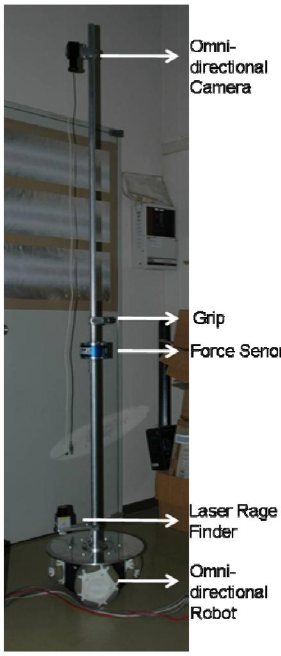

Fig. 1. Prototype of the omni-directional type cane robot

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mounted on the RT Walker. Whereas, this distance is not a significant feature for all possible falling cases, especially for a lateral falling-down. This will be further analyzed in the following. Vishwakarma proposed a fall model and an adaptive background subtraction method to detect human fall from video clips [12]. But background subtraction method is only applicable when there is an immovable background in the processed videos. Some other fall detection methods including wearable sensor based systems, acoustic based systems and video based systems can be found in [13].

2. INTELLIGENT CANE ROBOT SYSTEM

2.1 Mechanism of Cane Robot

In this section, we introduce a prototype system of omni-directional type cane robot shown in Fig. 1, which is developed to help elderly walking.

The cane robot consists of an omni-directional mobile base, a metal stick and sensor groups including the force sensor, the CCD camera and the LRF.

The omni-directional mobile base comprises three commercially available omni-wheels and actuators, which are specially designed for walker systems. Despite the small size, the load capacity of this mobile base is up to 50 kilograms.

The CCD camera is used to monitor the head position of the user. The LRF measures the distance between the stick and knees of the user, which plays an important role in the function of fall-prevention [10].

A six-axis force/torque sensor attached to the stick is used as the main control input interface.

2.2 Control Architecture

There are many possible walking modes during the usage of the cane robot. Hirata et al considered three modes including ‘normal walking’, ‘stop’ and ‘emergency’ in their studies [10]. In our previous study, we divided these rough modes further. Normally, different control scheme is required for different walking mode. Considering the high-level discrete walking modes and low-level motion control scheme based on continuous sensor signals, hybrid system theory is selected as the mathematical tool for the

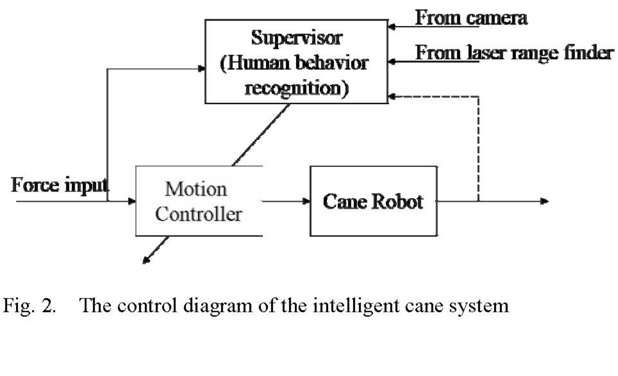


Fig. 2. The control diagram of the intelligent cane system

modeling and control design. A hierarchical control architecture is proposed, which is depicted by Fig. 2.

In the high-level supervising module, current walking mode is estimated from sensor signals. The inferred human behavior is taken as the input of the low-level motion controller module. In our previous study, a novel motion control scheme was investigated based on online resolved human intentional direction [10]. In this study, we pay more attention to the emergency situation during human walking. A simple two-state finite state machine (FSM) model is implemented in the supervisor, which is depicted in Fig. 3.

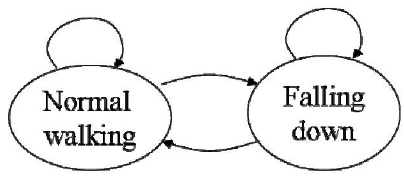


Fig. 3. Two-state finite state machine model in the supervisor

3. FALL MODEL AND FALL DETECTION

3.1 Fusion Method and Fall Model

In [11], Hirata used the distance between the user and RT Walker as a feature to detect if the user is falling down or not. Whereas, the falling state correctly cannot be reflected only by the position of the legs in many cases. Therefore, in our study the walking user is monitored simultaneously by a camera and a LRF as shown by Fig. 4.

As shown in Fig. 5-(a), possible falling states include ‘forward falling’, ‘backward falling’ and ‘sideward falling’. Here state ‘sideward falling’ consists of all falling cases

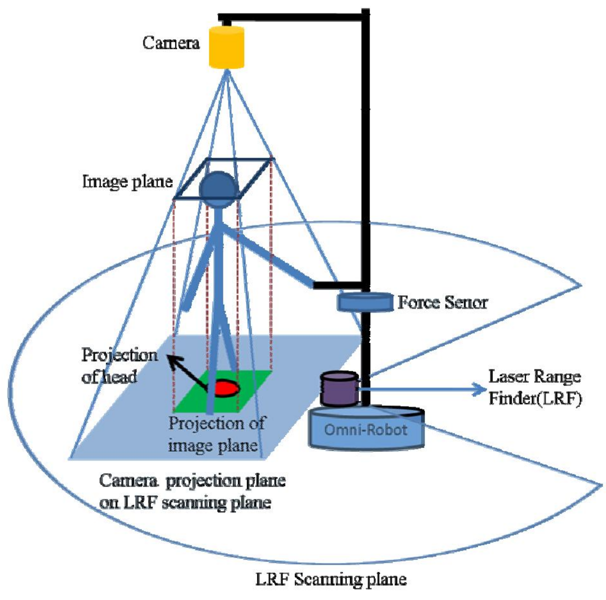
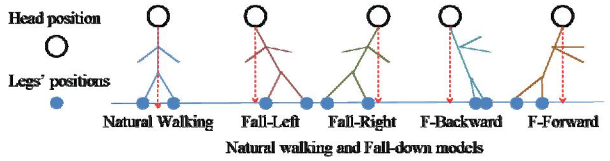
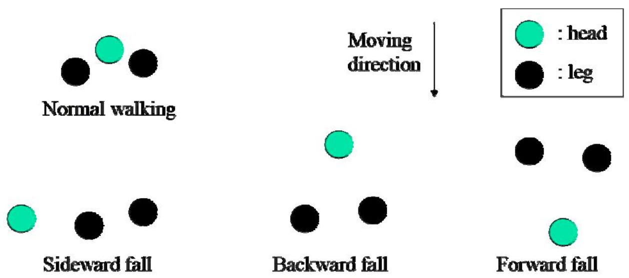


Fig. 4. Walking state is monitored simultaneously by a camera and a laser range finder (LRF)

except forward and backward falling. Through appropriate coordinate transformation, the walking state can then be represented in a 2D space, which is depicted in Fig. 5-(b). Two kinds of circles are used to indicate the positions of the user's head and legs.



(a) Normal walking and possible falling states



(b) Representation in the 2D top view

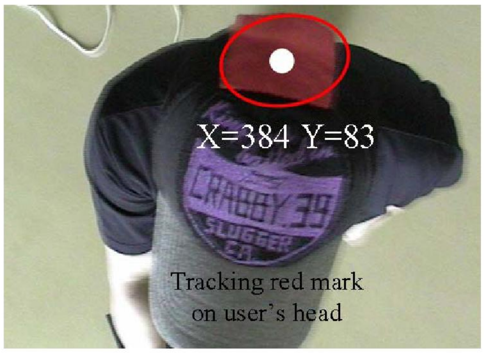
Fig. 5. Normal walking and fall model

The sensory information acquisition scheme is described by Fig. 6. The user wears a hat marked with a red pat during operating the cane robot (see Fig. 6-(a)). The head position is monitored by the CCD camera using color tracking algorithm. Fig. 6-(b) shows the data of one scan using the LRF. All the possible data points indicating the legs are classified into two groups using online K-mean algorithm. Each group denotes the left or right leg respectively.

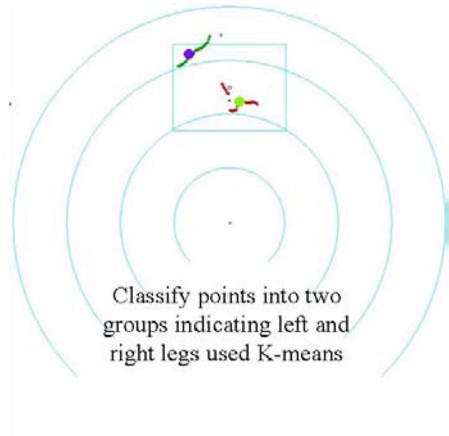
To obtain a data fusion from the two sensors, we integrate the two kinds of data into the image coordinate, as depicted by Fig. 7. The heights of the CCD camera and the user are denoted by *Ch* and *Uh*, respectively. A rectangular area of the LRF scan plane indicates the projected part to the image coordinate. $L1$ and $L2$ are used to denote the length and the width of this area. The size of the image coordinate is 640*480 pixels.

Obviously, the most important feature indicating the user's falling state is the distance d between the head and the center of two legs. While the user is walking normally, the value of d should fluctuate around a small constant. This constant and the fluctuation differ from different people. When the user is falling down, the distance d will increase suddenly in a certain direction.

We investigate the distribution of the distance d during the normal walking state. In [11], similar distribution was regarded as normal distribution and estimated to infer the user's walking state. In this study, we use Dubois possibility



(a) Tracking head position using the CCD camera (a example frame)



(b) Tracking legs' positions using the LRF (the bigger filled circles indicating the positions of the two legs)

Fig. 6. Acquisition of sensory data

theory [14] to describe the distribution of the distance d during the normal walking state.

The procedure starts by constructing the data histograms for the distance d during normal walking state. The number of bins h for a histogram is experimentally determined. Each bin is represented by the center of the interval denoted by y_j. The height of each bar is the number of learning points, located in this bin.

The probability distribution $\{p(y_j): j = 1,2,\cdots,h\}$ is calculated by dividing the height of each bin by the total number of learning points belonging to the same class. The possibility distribution $\{\pi(y_j): j = 1,2,\cdots,h\}$ is deduced from the probability distribution by the bijective transformation of Dubois and Prade defined by

$$\pi(y_k) = \sum_{j=1}^{h} \min\left[p(y_k), p(y_j)\right]. \quad (1)$$

The membership functions $\mu(\cdot)$ that characterize the fuzzy set '*normal walking*', is finally calculated from the corresponding possibility distributions by linear interpolation. Typical membership functions are given in section 4.

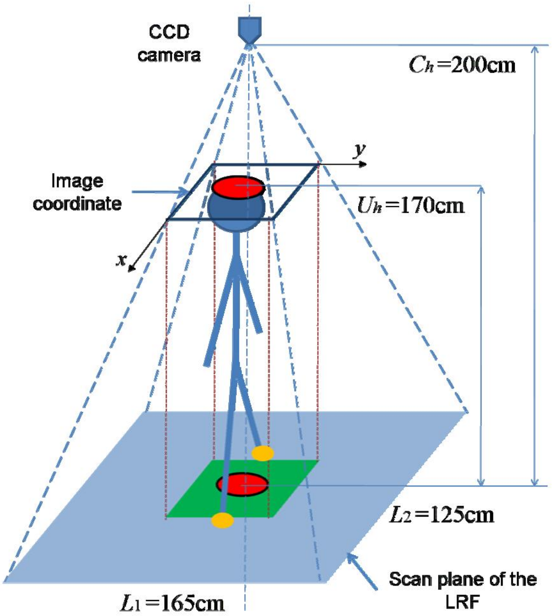


Fig. 7. An example of integrating of two kinds of sensory data

3.2 Fall Detection

The fall detection is implemented by a very simple rule, which is illustrated as follows: (assuming the human walking behavior is monitored at discrete times, *t* denotes the current time)

$$IF\ \ \mu(d(t)) < c\ \ and\ \ \mu(d(t-1)) < c$$

Then a fall is detected.

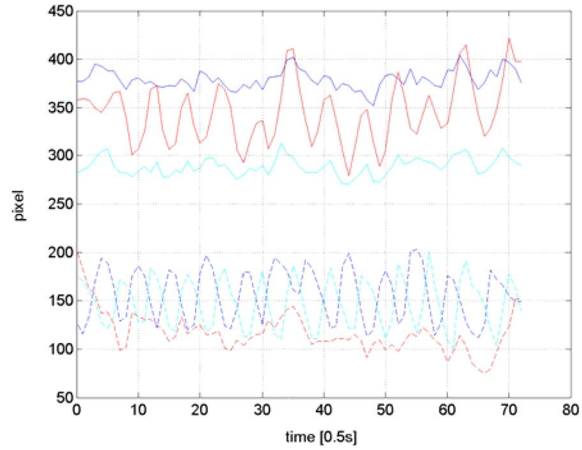
Constant *c* is a small positive number which indicates a very low possibility of '*normal walking*' state.

4. Experiments

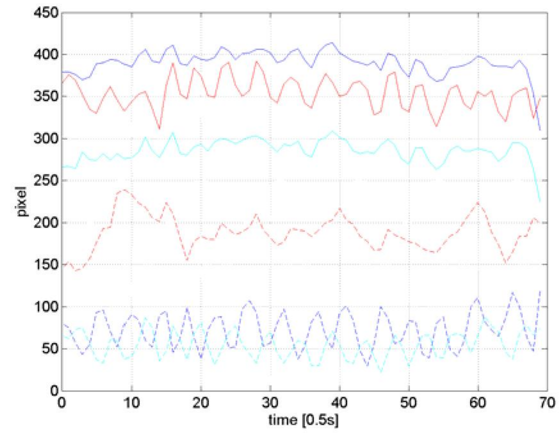
In this section, we experimented with the cane robot to illustrate the effectiveness of the proposed methods. First, the possibility distribution of 'normal walking' state is investigated. Then the validity of fall detection method is verified by experiments.

4.1 Experiments of Normal Walking

Two university students utilize the cane robot realizing normal walking in these experiments. The first student walked naturally during operating the cane robot, while the other one pretended to be a stooped old person walking with the help of the cane robot. The original fused position data



(a) The original legs and head position data of subject A



(b) The original legs and head position data of subject B

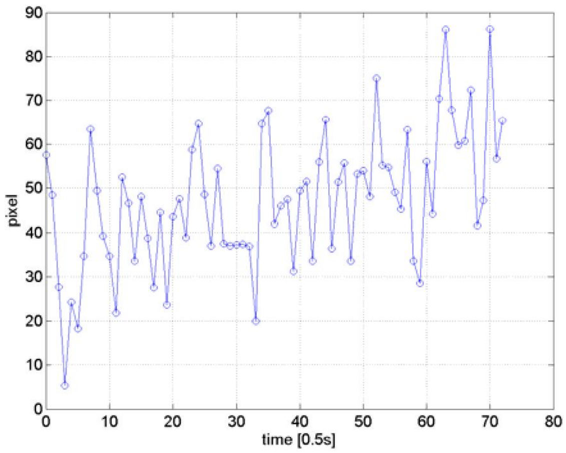
Fig. 8. The original fused position data. (The solid and broken lines denote the x and y axial coordinate value respectively. The positions of head are plotted using red lines and the leg positions are plotted using other colors.)

are shown in Fig. 8. The feature distances of both cases are computed and depicted by Fig. 9. Choosing the number of bins as 7, the membership functions are obtained and plotted in Fig. 10. The distance *d* is normalized into the interval [0, 200].

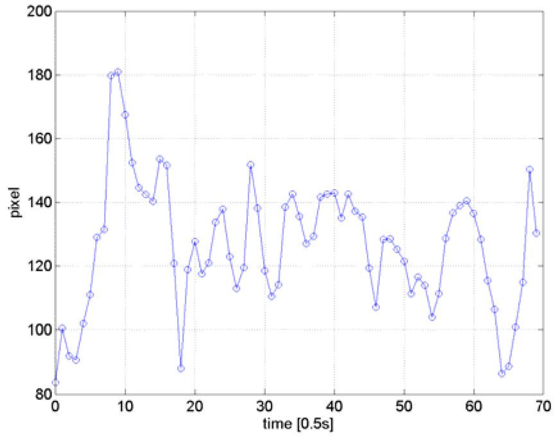
As shown in Fig. 9, the average value of *d* of subject B is much bigger than that of subject A. This is because subject B who pretended an old person was bending forward during walking.

4.2 Experiment of Fall Detection

In this experiment, subject A pretended to fall down during walking. The fall detection rule described in section 3.2 was applied in the experiment. Constant *c* was chosen as 0.2. The fall was detected promptly as shown by Fig. 11. The original video clips from just before to just after the detection time instant are also shown by Fig. 12.



(a) The distance *d* of subject A



(b) The distance *d* of subject B

Fig. 9. The computed feature distance *d* of both subjects

5. Conclusion

A new cane robot is designed to help the elderly walk. To prevent the user from falling down, a new fall detection scheme is proposed in this study. This scheme is based on the sensor fusion of different sensor resources. Fall model is created by using the simultaneous monitored information of the head's and the legs' positions. The effectiveness is confirmed through experiments.

Future work will focus on the investigation of fall prevention measures

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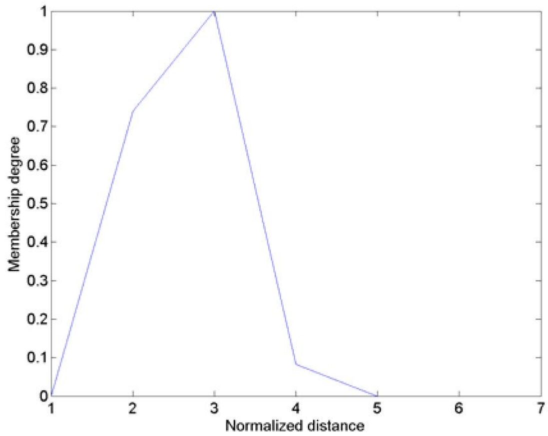
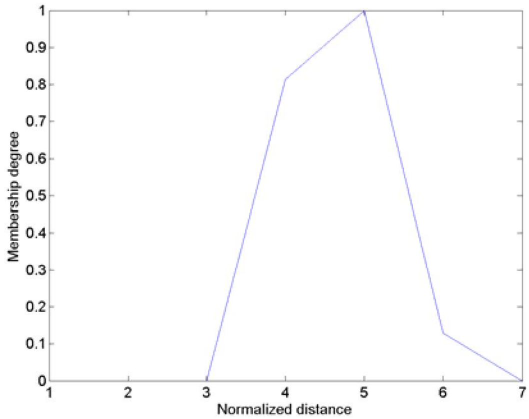


(a) The possibility distribution of distance *d* of subject A



(b) The possibility distribution of distance *d* of subject B

Fig. 10. The possibility distributions of feature distance *d* of both subjects

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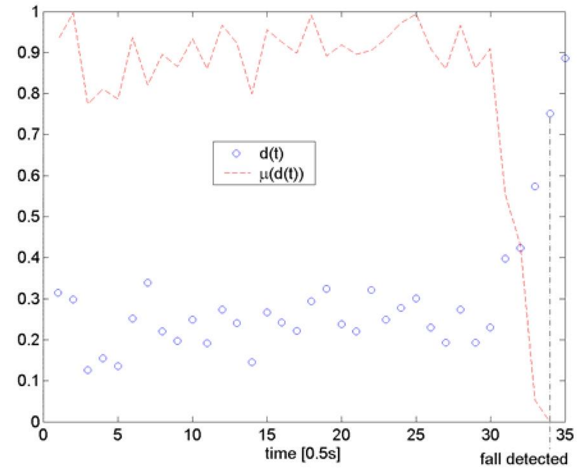

Fig. 11. The fall detection result

Fig. 12. The video clips around the detection time instant

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