Implementation of a Monitoring System for Fall Detection in Elderly Healthcare

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Abstract

Falls are a major problem for elderly living independently. The World Health Organization reports that injuries due to falls are the third most common cause of chronic disability. We propose an automated monitoring system that identifies faces in a given area, collects data such as speed of movement, and triggers an alarm if these data suggest the person has fallen. Our system does not suffer the problems with the existing commercial devices such as social alarms, e.g., a wristwatch with a button that must be activated by the subject and wearable fall detectors comprising accelerometers and tilt sensors.

Keywords: Fall detection; Monitoring system; Face detection; Elderly; webcam

1. Introduction

Injuries sustained among the elderly because of falls are a major problem worldwide. 28\%–35\% people in the age group of 65 and over suffer at least one fall in a year. The risk of falling increases with age, and, in two cases out of three, the accident occurs at home. It has been observed that people who suffer a fall at home and are left unattended for an hour or more usually die within six months of the accident. In the last few years, many commercial devices have been developed for the automatic and nonautomatic detection of falls [1][2][3][4], such as a social alarm, which is a wristwatch with a button that is activated by the person in case he/she suffers a fall, and wearable fall detectors, which are based on combinations of accelerometers and tilt sensors. However, these devices may present serious problems. The main problem with social alarms is that the button is often unreachable after a fall, especially when the person is panicked, confused, or unconscious. In the case of wearable detectors, the main problems are that they may produce false alarms and that the elderly often tend to forget to wear them [5][6][7]. To overcome these problems, we propose a system with fall detection capabilities for monitoring the elderly without any user intervention. In-home video cameras present several advantages over sensors: they are less intrusive because they are installed on buildings (not worn by users), they are able to detect multiple events simultaneously, and the recorded video can be used for post verification and analysis.

In this paper, we present an automated monitoring system based on image processing in real time; this system detects the face of a person in a given area, collects data such as the speed of movement of the person, and determines whether the person has suffered a fall; an alarm is triggered immediately upon the detection of a fall.
2. Monitoring System

In this section, we describe the monitoring system and its main functions. The system detects the face of a person in a given area, collects data (speed of person’s movement, distance between face and webcam, percentage of face present), determines whether a fall has occurred, and triggers an alarm upon fall detection.

### Architecture

A flow diagram of the monitoring system is shown below:

![Flow Diagram of Monitoring System](image)

**Fig. 1. Flow Diagram of Monitoring System**

#### 2.1 Webcams

First, a number of webcams are used to detect a person’s movement in a given area. The system consists of more than one webcam to cover the entire area to be monitored. Based on the presence of the face according to the webcam, a switch will be done to the other webcam. So at this phase, we have images of the person’s movement that will be processed later.

#### 2.1.1 Skin color and HSV detection

The images captured by the webcams are then processed by the system to detect skin color. This is an effective technique for determining whether an image contains a face or hands. In this technique, the appropriate threshold values are defined for all the pixels in a color space. Different color spaces are used to represent skin color pixels: RGB, RGB standard, HSV (or HSI), YCrCb, and HSV. After the detection of skin color pixels, image filtering (erosion and dilation) is carried out.

#### 2.1.2 Face detection

After identifying the skin areas, it is necessary to distinguish the face. For this, the shape of the detected object is compared with an ellipse. This correlation technique is very effective and efficient.

#### 2.1.3 Data collection

In this step, data such as the speed of the person’s movement, position of the person, and distance between the person and the webcam are collected to determine whether the person has suffered a fall.

#### 2.1.4 Distance between face and webcam

Once the above mentioned data are obtained, the distance the face and the webcam is estimated. The distance (in percentage) between the face and the webcam is estimated by comparing the width and length of each frame with the length and width of the original image, respectively. First, from the width and length of the first frame, its area (length \times width) is calculated in order to estimate the distance (%) in the initial image (we assume 50,000 pixel as maximum area).
Second, the following parameters are determined:

- **X = width/width0**
  
  width: width of the detected face in each frame
  width0: width of the detected face in the initial frame

- **Y = length/length0**
  
  length: length of the detected face in each frame
  length0: length of the detected face in the initial frame

Third, the distance (%) is estimated for the current frame using the value of either X or Y, whichever is closest to 1. This is because if the person detected by the camera turns his/her face up/down or to the right/left, only one parameter will change. If the person turns the face left/right, the width varies while the length remains almost equal to the initial length, length0. In a similar manner, if the person moves the face up/down, the length varies and the width remains almost equal to the initial width, width0.

### 2.1.4.2 Face presence

For the effective surveillance of an elderly person and detection of fall, a large field of view is necessary to track the person’s movements in an area. To satisfy this requirement, more than one webcam is used in the proposed system. The percentage of face in the images captured by a webcam is calculated. Thus, if the person moves away from the field of view of a webcam and the percentage of face present in each image captured by that webcam reduces, the control system automatically switches to another webcam. This percentage is obtained by using the following expression:

\[
Z = \frac{X}{Y} = \left(\frac{\text{width}}{\text{width0}}\right) \times \left(\frac{\text{length0}}{\text{length}}\right)
\]

### 2.1.4.3 Planar speed and actual speed

The planar speed of movement is calculated using the following formula:

\[
\text{Planar speed} = \frac{\text{distance}}{\text{time}} \text{ (pixel/s)}
\]

- distance: distance between two faces in consecutive frames (pixel)
- time: processing time between two consecutive images

The accuracy of fall detection depends on both the speed and the distance between the face and the webcam. The actual speed is defined as

\[
\text{Actual speed} = \text{planar speed} \times \left(\frac{1}{Z}\right)
\]

The actual speed can be classified into the following categories:

- **Low speed**: 0–200
- **Normal speed**: 200–400
- **Medium speed**: 400–600
- **High speed**: 600 and above

### 3. Results

In this section, we present the results obtained using the proposed monitoring system.

### 3.1 Distance between face and webcam
Table 1 – Planar and actual speeds calculated on basis of distance between face and webcam

<table>
<thead>
<tr>
<th>Frame</th>
<th>Width</th>
<th>Length</th>
<th>Surface</th>
<th>X = width/width0</th>
<th>Y = length/length0</th>
<th>Zoom (zoom %)</th>
<th>Planar Speed (pixel/s)</th>
<th>Actual speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>113</td>
<td>159</td>
<td>17967</td>
<td>1</td>
<td>1</td>
<td>35.934%</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>104</td>
<td>148</td>
<td>15392</td>
<td>0.9203</td>
<td>0.9308</td>
<td>33.44%</td>
<td>6.3434</td>
<td>18.97</td>
</tr>
<tr>
<td>7</td>
<td>94</td>
<td>133</td>
<td>12502</td>
<td>0.8318</td>
<td>0.8364</td>
<td>30.05%</td>
<td>21.211</td>
<td>70.59</td>
</tr>
<tr>
<td>9</td>
<td>81</td>
<td>114</td>
<td>9234</td>
<td>0.7168</td>
<td>0.7169</td>
<td>25.76%</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>15</td>
<td>56</td>
<td>81</td>
<td>4536</td>
<td>0.4955</td>
<td>0.5094</td>
<td>18.30%</td>
<td>6.2192</td>
<td>33.98</td>
</tr>
<tr>
<td>16</td>
<td>55</td>
<td>78</td>
<td>4290</td>
<td>0.4867</td>
<td>0.4905</td>
<td>17.62%</td>
<td>8.6235</td>
<td>48.94</td>
</tr>
</tbody>
</table>

In the above table, frames 5 and 15 have almost the same planar speed but different zoom (z) values. Therefore, the actual speeds are different.

3.2 Face presence

Table 2 – Face presence

<table>
<thead>
<tr>
<th>Frame</th>
<th>Width</th>
<th>Length</th>
<th>Surface</th>
<th>X</th>
<th>Y</th>
<th>Z</th>
<th>Z (zoom %)</th>
<th>Face presence (%)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>157</td>
<td>203</td>
<td>31871</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>63.74%</td>
<td>100%</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>131</td>
<td>193</td>
<td>25283</td>
<td>0.8344</td>
<td>0.9507</td>
<td>0.8776</td>
<td>60.59%</td>
<td>87.76%</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>73</td>
<td>172</td>
<td>12556</td>
<td>0.4219</td>
<td>0.8473</td>
<td>0.5488</td>
<td>54.01%</td>
<td>54.88%</td>
<td>Switch to another webcam</td>
</tr>
<tr>
<td>10</td>
<td>101</td>
<td>189</td>
<td>19089</td>
<td>0.6433</td>
<td>0.9310</td>
<td>0.6909</td>
<td>69.34%</td>
<td>69.09%</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>132</td>
<td>192</td>
<td>25344</td>
<td>0.8408</td>
<td>0.9458</td>
<td>0.8889</td>
<td>60.29%</td>
<td>88.89%</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>140</td>
<td>198</td>
<td>27720</td>
<td>0.8917</td>
<td>0.9754</td>
<td>0.9142</td>
<td>62.17%</td>
<td>91.42%</td>
<td></td>
</tr>
</tbody>
</table>

3.3 Fall detection
Fig. 4. Frames showing face detection and tracking

### Table 3 – Fall detection

<table>
<thead>
<tr>
<th>Frame</th>
<th>Width</th>
<th>Length</th>
<th>Surface</th>
<th>X</th>
<th>Y</th>
<th>Zoom (zoom %)</th>
<th>Planar speed (pixel/s)</th>
<th>Actual speed</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>84</td>
<td>85</td>
<td>7140</td>
<td>1</td>
<td>1</td>
<td>14.28%</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>102</td>
<td>91</td>
<td>9282</td>
<td>1.2143</td>
<td>1.0701</td>
<td>15.28%</td>
<td>80.6741</td>
<td>527.97</td>
<td>Medium speed</td>
</tr>
<tr>
<td>3</td>
<td>83</td>
<td>90</td>
<td>7470</td>
<td>0.9881</td>
<td>1.0588</td>
<td>15.12%</td>
<td>63.7637</td>
<td>421.72</td>
<td>Medium speed</td>
</tr>
<tr>
<td>4</td>
<td>82</td>
<td>91</td>
<td>7462</td>
<td>0.9762</td>
<td>1.0706</td>
<td>15.29%</td>
<td>40.3230</td>
<td>263.72</td>
<td>Normal speed</td>
</tr>
<tr>
<td>5</td>
<td>75</td>
<td>86</td>
<td>6450</td>
<td>0.9829</td>
<td>1.0118</td>
<td>14.45%</td>
<td>85.8540</td>
<td>594.15</td>
<td>Medium speed</td>
</tr>
<tr>
<td>6</td>
<td>80</td>
<td>76</td>
<td>6080</td>
<td>0.9524</td>
<td>0.8941</td>
<td>13.60%</td>
<td>29.5707</td>
<td>217.43</td>
<td>Normal speed</td>
</tr>
<tr>
<td>7</td>
<td>81</td>
<td>89</td>
<td>7209</td>
<td>0.9643</td>
<td>1.0471</td>
<td>14.95%</td>
<td>57.8031</td>
<td>386.64</td>
<td>Medium speed</td>
</tr>
<tr>
<td>8</td>
<td>80</td>
<td>85</td>
<td>6800</td>
<td>0.9524</td>
<td>1</td>
<td>14.28%</td>
<td>87.8369</td>
<td>615.10</td>
<td>High speed (Fall detection) → Alarm</td>
</tr>
</tbody>
</table>

### 4. Conclusion

The elderly represent the fastest growing segment of the population around the world. Therefore, public health service institutions are likely to face budget problems. This will increase the demand for services aimed at helping the elderly live longer in their own homes and improving their quality of life. The proposed monitoring system offers complete activity monitoring and automatic fall detection and allows the detection of a distress situation by triggering an alarm upon fall detection. Test results show that the system is reliable and will offer a number of advantages such as reducing hospitalization costs by improving the living conditions of elderly people.

### 5. References