Detection of Abnormal Action for Monitoring System of Aged People and Industrial Robot

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Abstract

In this paper, a monitoring system for aged people is proposed, because Japan will be a serious aging society rapidly. This system learns aged people's usual actions automatically in about one week and detects his/her abnormal action by observing the room with a simple camera such as CCD. For the detection method, Eigenspace Method is used which is excellent in compression of image data and calculation of the correlation among images. Parametric Eigenspace Method(PEM) is also used to detect abmormalities such as the speed of the action. The proposed system can be applied to various monitoring systems. As one of such applications, a monitoring system for industrial robots in the factories is presented.

1 Introduction

Japan is now a serious aging society and this problem will be more serious in the near future. Therefore, engineering support for aged people is required. As one of such support, we propose a system to detect aged people's abnormal action by observing the room with a camera. If he/she acts differently from usual behavior, the proposed system detects it, and immediately reports to his family or medical institution. Fig.1 shows an example of care system for aged people, in which the proposed system is useful.

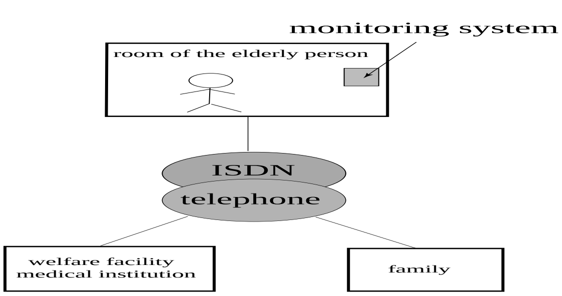


Fig. 1: Example of care system for aged people

If such system has been realized, it is also possible to apply to other systems, for example, observation of robots in the factory and traffic.

First, detection method of aged people's abnormal action using Eigenspace Method and Parametric Eigenspace Method(PEM) is presented. Then the proposed monitoring method is applied to the observation of industrial robots.

2 Monitoring system of aged people

2.1 Features of the system

First, the system automatically learns his/her normal actions and behavior pattern in about one week, after that, detects his/her abnormal actions based on the learned result. The proposed system has the following features:

(1) The system automatically learns actions without knowledge of the structure of his/her room such as position of the entrance, bed or table, and knowledge of the regular behavior pattern of human being.

(2) The system don't understand the meaning of his/her actions such as going to the bathroom, eating or sleeping on the bed. The system only classifies actions, for example, A, B, C, $\cdots$.

(3) The system occationally judges normal action abnormal by mistake, however it doesn't matter because it gives some opportunities to communicate with his/her family or medical institution.

2.2 Classification of abnormalities detected with a camera

Abnormalities of aged people's actions which can be detected by image information are defined as follows:

(Ab-1) different action from reference

If he/she acts differently from the learned action, the system should judge it abnormal, for example, falling down suddenly or struggling on the bed.

(Ab-2) speed of action

In general, aged people act slowly, therefore, if he/she acts very quickly or slowly, for example, slips off the step or other people enter the room, the system should judge it abnormal.

(Ab-3) direction of action

This is an important element in observation of robots in the factory and traffic.

(Ab-4) behavior pattern

For example, if he/she goes out at midnight or sleeps all day, the system should judge it abnormal. That is, the system should learn his/her usual behavior pattern and detect the different behavior pattern based on it.

After the learning stage, the system detects the above four abnormalities (Ab-1)∼(Ab-4).

3 Detection of abnormal action using Eigenspace Method

3.1 The methods of human motion analysis

Many methods for action recognition from image sequence have been proposed, for example, DP matching[1], HMM[2], and Temporal Templates[3].

We want to realize the simpler and real time system using a CCD camera or a camera of TV telephone, therefore, we analyze image sequences using Eigenspace Method without a reconstruction of 3D structure.

3.2 Extraction of the distance among images

In this paper, we consider the images of abnormal actions have low correlation to the learned images. To extract the distance between images, we use Eigenspace Method[4, 5] which is excellent in calculation of the correlation among images and compression of image data.

3.2.1 Eigenspace Method

We will now mention Eigenspace Method used both to classify actions and to detect abnormalities.

An normalized image data at time t is represented as $\boldsymbol{y}(t)$. The covariance matrix of image data set $\boldsymbol{y}(t)$ is represented by

$$\boldsymbol{Q} = \sum_{t=1}^{T} (\boldsymbol{y}(t) - \boldsymbol{c})(\boldsymbol{y}(t) - \boldsymbol{c})^T \qquad (1)$$

where $\boldsymbol{c}$ is the mean vector for $\boldsymbol{y}(t)$. k eigenvectors $\boldsymbol{e}_1$,$\boldsymbol{e}_2$, $\cdots$,$\boldsymbol{e}_k$ $(\lambda_1 \geq \cdots \geq \lambda_k \geq \cdots \geq \lambda_K)$ are determined by solving eigenvalue problem:

$$\lambda_j \boldsymbol{e}_j = \boldsymbol{Q}\boldsymbol{e}_j \qquad (2)$$

The k-dimensional subspace spanned by these eigenvectors is called the eigenspace. Then, one image vector is projected onto the eigenspace by

$$\boldsymbol{z}(t) = [\boldsymbol{e}_1, \cdots, \boldsymbol{e}_k]^T (\boldsymbol{y}(t) - \boldsymbol{c}) \qquad (3)$$

The closer the projection points are in the eigenspace, the more highly correlated are the images. Thus, we can detect abnormality based on the distance in the eigenspace.

3.2.2 Parametric Eigenspace Method(PEM)

An image can be mapped to a point in the eigenspace, therefore a sequential movement can be represented as a smooth locus in the eigenspace as shown in Fig.2. This is called Parametric Eigenspace Method(PEM)[4, 5].

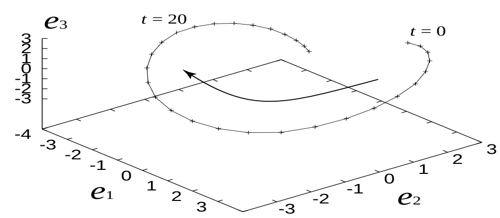


Fig. 2: Parametric Eigenspace Method(PEM)

3.3 Abnormality detection process of the proposed system

Fig.3 shows the abnormality detection process. In the learning stage, Self-Organizing Map(SOM)[6, 7], one of the unsupervised, competitive learning method, is used. In the case of the monitoring system of aged people, his/her actions such as sleeping, eating, and watching TV may occur within the each fixed region in the image. That is, some similar images according to actions frequently appear, and we extract these images using SOM. Input images are classified (action A, B, C, $\cdots$) using the "universal" eigenspace constituted from these extracted images, and analized according to the action in each local region to be focused. Detail of this learning method is described in [8].

3.4 Detection of abnormal action using Eigenspace Method

After the learning of normal actions, abnormality detection using Eigenspace Method starts by classifying input images (action A, B, C, $\cdots$).

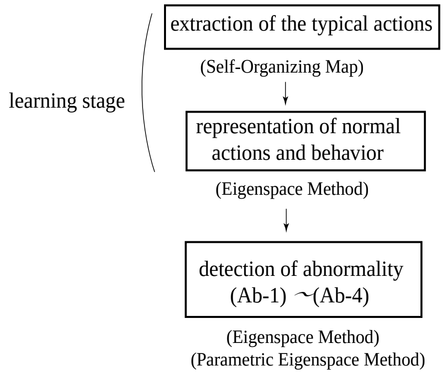


Fig. 3: Abnormality detection process

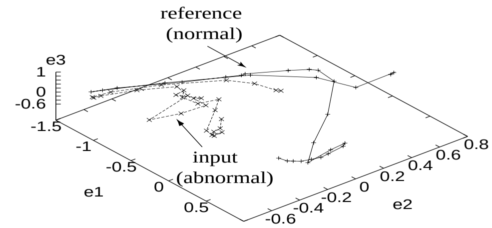


Fig. 7: The locus in three-dimensional eigenspace (reference pattern and input pattern)

3.4.1 Detection of different actions from reference (Ab-1)

As stated above, the closeness in the eigenspace represents the correlation among images, therefore, we can detect the different action from reference as lower correlation images by the distance in the eigenspace. We search the reference point closest to the projected point $\boldsymbol{z}^{(j)}(t)$ of an input image onto the eigenspace of the jth action by

$$d_1^2 = \min_i \|\boldsymbol{z}^{(j)}(t) - \boldsymbol{f}_i^{(j)}\|^2 \quad (4)$$

where $\boldsymbol{f}_i^{(j)}$ are the reference points in the eigenspace of the jth action. If d_1 is larger than the threshold, the system judges the action abnormal.

$$d_1 > d_{\text{thre}} \quad \rightarrow \text{abnormal}$$

When the eigenspace is constituted from the reference images(30 frames) sitting on a chair such as Fig.4, the input image sequence(30 frames, fall down from $t = 10$) such as Fig.5($t = 15$) and Fig.6($t = 19$) are represented in the eigenspace as shown in Fig.7.

Fig. 4: Reference pattern

Fig. 5: Input pattern($t = 15$)

Fig. 6: Input pattern($t = 19$)

Fig.8 shows the minimum distance d_1 in three-dimensional eigenspace searched by (4). The minimum distance d_1 comes to be large after $t = 10$ when the human collapses from the chair. Thus, lower correlation images of abnormal action can be detected by the distance.

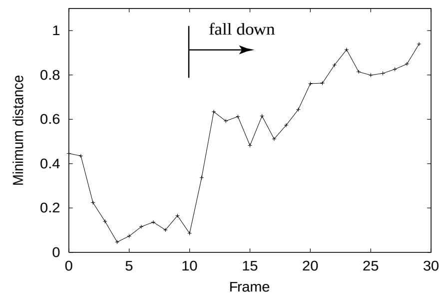


Fig. 8: The minimum distance d_1 in three-dimensional eigenspace

3.4.2 Detection of the speed and direction of action (Ab-2,Ab-3)

To detect the speed and direction of action, we compare betweeen the loci by (5) using Parametric Eigenspace Method(PEM)[4, 5]. The locus closest to that of the input image sequence $\boldsymbol{z}^{(j)}(t)$ is found by

$$d_2^2 = \min_{a,b} \sum_{t=1}^{T} \|\boldsymbol{z}^{(j)}(t) - \boldsymbol{f}^{(j)}(at+b)\|^2 \quad (5)$$

$$\tilde{a} = \arg\min_{a} \sum_{t=1}^{T} \|\boldsymbol{z}^{(j)}(t) - \boldsymbol{f}^{(j)}(at+b)\|^2 \quad (6)$$

where a is the time stretch factor, and b is the time shift factor. Then, the absolute value of $\tilde{a}$ represents the speed of action and the sign of $\tilde{a}$ represents the direction of action. That is,

if	$\tilde{a} < -1$,	opposite direction,	quickly
if	$-1 \le \tilde{a} < 0$,	opposite direction,	slowly
if	$0 \le \tilde{a} < 1$,	same direction,	slowly
if	$1 \le \tilde{a}$,	same direction,	quickly

Fig.9 shows one of the reference images(30 frames) walking from the right side to the left side, and Fig.10 shows the locus in the eigenspace. Two kinds of image sequences(14 frames) are inputed. They are (I)walk more quickly in the same direction, (II)walk more slowly in the opposite direction. Each locus in the eigenspace is shown in Fig.11.

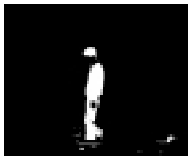


Fig. 9: Example of reference image

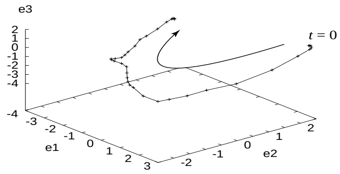
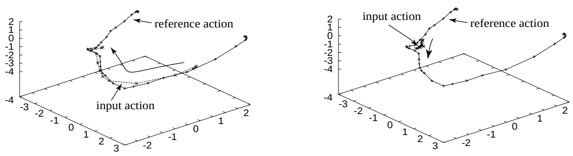


Fig. 10: The locus in three-dimensional eigenspace (reference)



(I) quickly, same direction

(II) slowly, opposite direction

Fig. 11: The locus in 3-dimensional eigenspace

$\tilde{a}$ and d_3 when the closest locus is searched using (5) are given as follows. The dimensions of the eigenspace are $3 \sim 5$. In the case of (I), $1 \leq \tilde{a}$. In the case of (II), $-1 \leq \tilde{a} < 0$. This result shows the speed and direction of action are estimated by $\tilde{a}$.

	(I)			(II)		
k	$\tilde{a}$	$\tilde{b}$	d_3	$\tilde{a}$	$\tilde{b}$	d_3
3	1.39	6.57	3.20	−0.17	27.26	1.15
4	1.45	6.44	3.55	−0.33	27.16	2.10
5	1.48	6.34	3.93	−0.30	27.12	2.62

4 Application to a monitoring system for industrial robots

Fig.12 shows the realization image of a monitoring system for industrial robots. This system, set by the robot, automatically detects different movement from reference and immediately reports to the operator.

In the current industrial robots in the factory, abnormalities are usually detected by servo system and robot controller. However, abnormalities such as bend of axis, vibration, and the faults of sensors cannot be detected. Therefore, the proposed monitoring system is very useful.

In this section, abnormality detection method using Eigenspace Method is applied to the monitoring

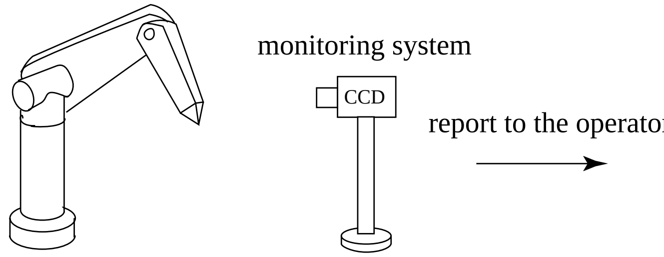


Fig. 12: Realization image of monitoring system for industrial robots

system for industrial robots and the experiment results using 2-axis robot are presented.

4.1 Features of the system

The proposed monitoring system has following advantages:

[1] We don't need to go about to observe the robots in the factory and are safe from danger.

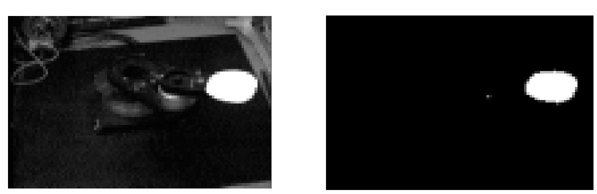
[2] We can grasp the situation early and exactly by the obtained image sequence when some accident occurs.

[3] This system is inexpensive because a simple camera such as CCD is used.

[4] There is no need to receive any signal from the robot controller because it only observes with a camera.

[5] It is easy to install to any industrial robots.

It is difficult to extract the region of the robot manipulator by simple subtraction because the background image in the factory is very complicated. Therefore, it is appropriate to attach a colored marker to the end of robot and extract it using color information. In this experiment, we attach a white marker and extract it by simple binarization as shown in Fig.13.



(a) the original image (b) the binarized image

Fig. 13: Extraction of the end of the robot

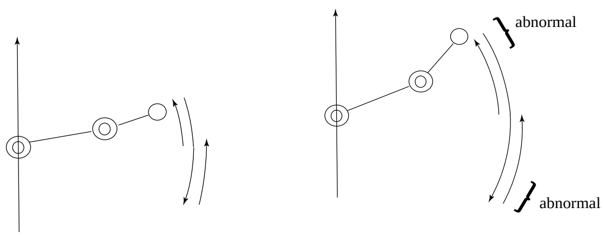
4.2 Detection of abnormal movement

To detect different movement from reference, Eigenspace Method and Parametric Eigenspace Method(PEM) are used in the similar way to the monitoring system of aged people.

In the experiment using 2-axis robot, we give the movement like a pendulum shown in Fig.14 by giving the sinusoidal position input to each axis, and detect different movement and speed.

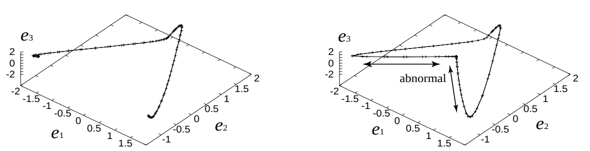
4.2.1 Detection of the different movement

The movement shown in Fig.14(a) is learned and eigenspace is constituted. Then, the abnormal movement having double amplitude shown in Fig.14(b) is input, that is, it is abnormal when the robot comes to the both ends. Fig.15(a)(b) show each projected points onto the eigenspace.



(a) reference movement (b) input movement

Fig. 14: Movement of the robot



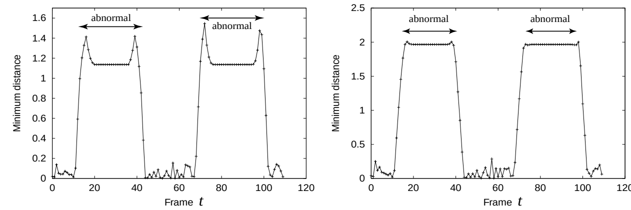
(a) reference image sequence (b) input image sequence

Fig. 15: Projected locus in the 3-dimensional eigenspace

As mentioned above, the distance in the eigenspace represents the correlation among images. Thus, we can detect different movement from reference by the magnitude of d_1 in the equation (4). Fig.16(a)(b) show the minimum distance d_1 in the 3-dimensional and 5-dimansional eigenspace.

4.2.2 Detection of the different speed

When the usual movement shown in Fig.15(a) is learned, the following three pattern of movement are given. T is the period of the sinusoidal position reference.



(a) 3-dimensional eigenspace (b) 5-dimensional eigenspace

Fig. 16: Minimum distance d_1 in the eigenspace

(a) same speed as reference ($T = 24$[s] normal)
(b) quicker than reference ($T = 12$[s] abnormal)
(c) slower than reference ($T = 32$[s] abnormal)

Fig.17 shows the value of $\tilde{a}$ for input movements (a)∼(c). We can easily detect the abnormal speed of the robot by setting thresholds, for example, 1.25 and 0.75.

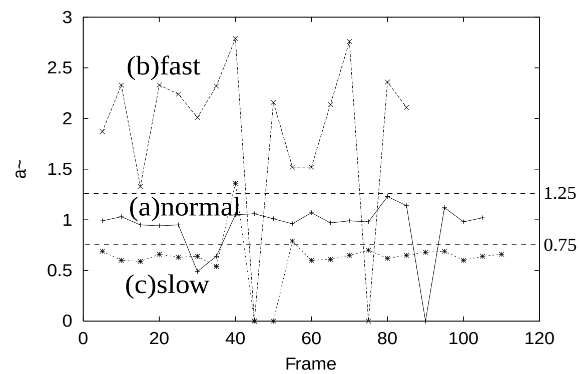


Fig. 17: Value of $\tilde{a}$ for input image sequences

5 Conclusion

In this paper, we have proposed the abnormality detection method for a monitoring system of aged people. We have applied Eigenspace Method to abnormality detection which is excellent in compression of image data and calculation of the correlation among images .

A human action is analized using Eigenspace Method. Sequential images of the action are represented by a locus in the eigenspace. We can detect the different action based on the distance of projected points onto the eigenspace, and the speed and direction of action by the introduced two parameters to characterize the loci using Parametric Eigenspace Method(PEM).

Some simulation results show the effectiveness of the proposed method. The proposed system is developed mainly for monitoring aged people, however, it can be applied to various systems. As one of such applications, a monitoring system for industrial robots in the factories has been proposed and some experiments using 2-axis robot show the effectiveness. In addition, it can be applied to many other monitoring systems, for example, observation of inpatients in hospital, traffic, and security monitoring in buildings and stores.

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