A Learning Method for Non-fixed Speed Gait Classification

Hongmin Xue
School of Computer Science and Technology, Xidian University, Xi'an, P.R.China
Shaanxi XueQian Normal University, Xi'an, P.R.China
Email: xuehongmin@163.com

Zhijing Liu
School of Computer Science and Technology, Xidian University, Xi'an, P.R.China
Email: liuzhijing@vip.163.com

***Abstract*—This paper presented a new human gait classification based on the notion that gait types can be analyzed into a series of consecutive postures types. Silhouettes are extracted using the background subtraction method and then human posture silhouettes features are represented by moment. In the learning stage, we propose a method for the establishment of the standard gait base matrix by the method of recursion. The incoming silhouettes and the database silhouettes are estimated comparison using the Moment Invariants Distance (MID) method. And the comparison result leads to a matrix. In the classification stage, the Minimal Standard Deviation (MSD) algorithm for vector of each motion type is proposed to deduce behavior classification of walker at flexible speed. Finally the method was validated in the outdoor environment an evaluation of eight kinds of gaits involving standing, bending, sitting, walking, jumping, crouching, uphill and downhill is given, followed by a comparison with other methods. The results show that the identification method presented in this paper has higher rate.**

***Index Terms*—Gait Classification, Moment Invariants, Standard Deviation, Centroid**

I. Introduction

With the improvement of computer processing and the development of image information and public security, Intelligent Video Surveillance System (IVSS) is widely used in train stations, bus stations, subways, airports, schools, and other public places. An active research topic in computer vision, IVSS in dynamic scenes attempts to detect, track and recognize walkers from video sequences, and further to describe and understand pedestrian behaviors on a more general scale. The ultimate goal is to develop IVSS to replace the traditional passive video surveillance system which proves ineffective as the cameras have too large a number for human operators to monitor them [2]. In short, the goal of IVSS is not only to make cameras in place of human eyes, but also to accomplish the entire surveillance task as automatically as possible [31-33].

Recognition of the abnormal pedestrian behavior is one of the most significant purposes of IVSS [1]. Effective use of a monocular camera for automatic surveillance can be made following a series of steps: motion detecting, objects tracking, behavior understanding and alarm. Though the detection of moving walkers can help to detect crimes, accidents, terrorist attacks, etc., it is hard to define "abnormal" in different scenarios. The most convenient way is an initial classification of the pedestrians' gaits, and then behavior validity can be made under specific scenarios.

Using gait as biometric information, Gait classification attempts to understand people by the characterization of their motion. It also includes efforts to classify different types of human activities, such as standing, lying, bending, sitting, walking, uphill and downhill action. The importance of human behavior classification grows evident with the increasing requirement for an intelligent and easy interaction between machines and human-inhabited environment. Research in the field has been being actively conducted, but the techniques available are too intuitive or computing-costly to be used for real-time applications. Thus, it is desirable to reduce the dimensionality of motion classification without the loss of its elementary features [24].

A learning method with prior exposure to the motion classification, which belongs to the work of the behavior understanding, is presented by the paper. Zhang et al.[31] describes a method for classifying the gaits based on Fuzzy Associative Memory (FAM) classifier. [32-33] also describe a method for classifying the gaits based on different classifier; therefore the paper makes three main contributions:

- An approach to deducing and generalizing gait classification simply from silhouette contour is proposed.
- A method for establishing different standard motion base by recursion is presented.
- A minimal standard deviation of vector method allowing efficient uncertain speed gait classification is proposed.

The paper is organized as follows. Section 2 briefly reviews some related works and Section 3 describes a method for silhouette extraction. Then, the algorithm for

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image similarity is presented in Section 4. Section 5 proposes the construction of motion sequence base, and Section 6 introduces a method of movement classification, the minimal standard deviation. Experimental results are presented in Section 7, followed by the conclusions part.

II. Related work

Owing to their complications, it is a challenge to classify human gaits automatically. Under outdoors circumstances, this classification is especially difficult. The task is challenging in these application due to the fact that 1) pedestrian's gait is flexible; 2) different people walk at different speed; 3) it is difficult to separate pedestrians from cluttered background in outdoor environment.

Some attempts at behavior classification have already been made. Meyer [3], one of the pioneers, has proposed a method for modeling several body parts and treating the background as mixture densities. Features for gait analysis, which are used to train HMM, are derived from the trajectories. One HMM represents each kind of gait.

Then, Pavlovic[4] carries out more works. He develops an approximate structured variation inference algorithm for Switching Linear Dynamic Systems (SLDS) and a globally convergent Dynamic Bayesian networks (DBNs) inference scheme. And 'Point Distribution Model' [7] is presented to distinguish the movements of walking and running. Between histograms of spatio-temporal templates and the wavelet coefficients on different scales, a comparison is made to show the significance of the known classification information [12]. A two-threshold, multidimensional segmentation algorithm is presents by Lu [15] to automatically decompose a complex motion into a sequence of simple linear dynamic models, and it do not need to make earlier supposition to the model quantity in the entire process and the duration of the task cycle. And also in 2005, the projection histogram is presented to classify the behavior [22].

Other investigators are engage in more researches. To solve the problem of the motion classification, Qualitative Normalized Templates framework is put forward by Chan [13]. In 2007, Juang proposed a method for neural fuzzy network [14], which can classify four main body postures, including standing, bending, sitting, and lying. Gaussian Processing Annealed Particle Filter Tracker is introduced by Raskin[17] to characterize different motion types. The duty-factor is presented by Fihl [20] to classify walking, jogging and running. An application is made of hierarchical chamfer matching, combined with particle filtering to divide commuters in the railway station into several classes [23]. Wang presents Gaussian mixture models based classification, which is a matching-based approach with the mean Hausdorff distance, and continuous hidden Markov model-based [18].

What is mentioned above is an overall analysis of all the prior researches on this topic. Previous algorithms fall into four major categories, which are probabilistic algorithm [3] [4] including HMM and DBNs, wavelet algorithm [12] [24], classifier algorithm [16] including Fisher and SVM and Neural Networks [14]. In another aspect, previous research objects fall into four major categories, namely, trajectories [3] [21], silhouette [5] [7] [14] [16] [18] [20] [22], projection histograms [22] [24], and joint angles respectively [13] [15] [17].

In recent years, despite the fact that considerable achievements have been accomplished in this field, some challenges still remain to be overcome. The optimal gait classification should classify motion with flexible speed, which can comprise the real-time surveillance system. For this goal to be achieved, the paper describes and evaluates an MSD algorithm for movement classification.

III. Silhouette Extraction

In the IVSS, at first the human body must be segmented from an image scene in the case of gait classification. Here, based on a background model construction, a background subtraction method is used for segmentation. Environmental models can be classified into 2-D models in the image plane and 3-D models in real world coordinates. Due to their simplicity, 2-D models have more applications. In this paper, classification is performed outdoors, applying a 2-D model with a single fixed camera.

A. Background Modeling

In this paper, an algorithm based on the statistical Gaussian model [30] is applied to estimate the background image, which is composes of initialization and updating. At an interval time M, the mean and the covariance of the brightness of every pixel are computed as the initially estimated background images, Viz. $B_0 = [\mu_0, \sigma_0^2]$, where

$$\mu_0(x,y) = \frac{1}{M}\sum_{i=0}^{M-1} f_i(x,y)$$
$$\sigma_0^2(x,y) = \frac{1}{M}\sum_{i=0}^{M-1}[f_i(x,y) - \mu_0(x,y)]^2 \quad (1)$$

After initializing the estimated background image, with the appearance of the new image, the parameters of background image should be updated self-adaptively according to the following formula. The updated image is $B_t = [\mu_t, \sigma_t^2]$, with

$$\mu_t = (1-\alpha)\mu_{t-1} + \alpha \times f_t$$
$$\sigma_t^2 = (1-\alpha)\sigma_{t-1}^2 + \alpha(f_t - \mu_t)^2 \quad (2)$$

Where α is a given constant and range from 0 to 1.

B. The Recognition of Moving Object

The goal of moving object detection is to extract change regions from background image in sequence images. The Background Subtraction [27] is the most widely used method of object detection. A simple method based on gradient filter, which is proposed in [25], is also used to eliminate shadow effect. Detailed steps of the complete processing algorithm can be found in [25]. To eliminate noise after segmentation, a simple method which is different from the one in [25] is used in this paper. It is the body's silhouette information that is only used in the successive posture classification. To eliminate the noise, the morphological operator, which includes the erosion and dilation operator with a structure of 3×3, is performed [26][14]. The result of refining silhouette is shown in Figure 1.

Figure 1. a) Original Frame b) Foreground Extraction

IV. Algorithm for Image Similarity

The most essential step in the process of body identification is the comparison of image similarity, because it can get the similarity degree between the current frames with the standard picture. Therefore, the key is how to find out the similarity degree of the two images. In this paper, an algorithm for image similarity based on moment invariants [10] is proposed.

A. Moment Invariants

Image recognition is the major branch of pattern recognition, and images can be classified due to their different features. Shape character can find wide applications in moment feature, for there is a direct relationship between the basic two-dimensional images and the moment. According to the visual perception, the primary features must be the shape, and the supplementary be the color characteristics in the process of body identification. Image shape is one of the essential characteristics of objects, and it has close relationship with the behavior target. In summary, the shape comparison algorithm can be divided into two categories, one of which is border-based method, such as Fourier descriptors and deformation template matching [29], and the other of which is region-based method, such as moment invariants. The former category merely uses the shape of the border, while the latter applies the regional information of the whole shape. M.K.Hu [10] firstly defined the continuous function moment and the fundamental feature of moment. In his view, moment means the layout of an image shape, which represents a description of the image on a high level, such as area, density, compactness, irregularity etc. Complete theoretical systems of moment invariants under translation, similitude and orthogonal transformations are given.

Assume that $f(x,y)$ is a continuous function of two-dimensional images, and $(p+q)$ order original moment is:

$$m_{pq} = \iint_{x,y\in\Omega} x^p y^q f(x,y)dxdy \tag{3}$$

Where $p,q = 0,1,2\cdots,\quad x,y\in\Omega$,and m_{pq} means the monomial projection of $f(x,y)$. Obviously m_{pq} is uniquely determined by $f(x,y)$, and conversely $f(x,y)$ is exclusively determined by m_{pq}. Because of the translation invariance of m_{pq}, $(p+q)$ order central moment is:

$$\mu_{pq} = \iint_{x,y\in\Omega} (x-\bar{x})^p (y-\bar{y})^q f(x,y)dxdy \tag{4}$$

Where $\bar{x} = \frac{M_{10}}{M_{00}}$ and $\bar{y} = \frac{M_{01}}{M_{00}}$.

Normalization $(p+q)$ order central moment η_{pq} :

$$\eta_{pq} = \frac{\mu_{pq}}{\mu_{00}^{\gamma}} \qquad \gamma = \frac{p+q+1}{2}\ (p+q = 2,3,......) \tag{5}$$

Hu[10] computed seven values from normalized central moments, which are invariant to translation, scale, mirroring, and rotation. A moment group $M_1\cdots M_7$ is derived of normalized third-order and second-order central moment.

$$\begin{cases} M_1 = \eta_{20}+\eta_{02} \\ M_2 = (\eta_{20}-\eta_{02})^2 + 4\eta_{11}^2 \\ M_3 = (\eta_{30}-3\eta_{12})^2 + (3\eta_{31}-\eta_{03})^2 \\ M_4 = (\eta_{30}+\eta_{12})^2 + (\eta_{21}+\eta_{03})^2 \\ M_5 = (\eta_{30}-3\eta_{12})(\eta_{30}-\eta_{12})[(\eta_{30}+\eta_{12})^2 - 3(\eta_{21}+\eta_{03})^2] \\ \quad +(3\eta_{21}-\eta_{03})(\eta_{21}+\eta_{03})[3(\eta_{30}+\eta_{12})^2-(\eta_{21}+\eta_{03})^2] \\ M_6 = (\eta_{20}-\eta_{02})[(\eta_{30}+\eta_{12})^2-(\eta_{21}+\eta_{03})^2] \\ \quad +4\eta_{11}(\eta_{30}+\eta_{12})(\eta_{21}+\eta_{03}) \\ M_7 = (3\eta_{12}-\eta_{30})(\eta_{30}+\eta_{12})[(\eta_{30}+\eta_{12})^2-3(\eta_{21}+\eta_{03})^2] \\ \quad +(3\eta_{21}-\eta_{03})(\eta_{21}+\eta_{03})\ [3(\eta_{03}+\eta_{12})^2-(\eta_{12}+\eta_{30})^2] \end{cases} \tag{6}$$

Aimed at improving efficiency, the rapid moment algorithm [28], which is proposed by Hatamian, is adopted by the paper to extract image moment feature. It turns two-dimensional image moment into two one-dimensional moments, which is followed by a calculation by the method of recursion. If this is done, it might significantly reduce the number of multiplication, as well as the number of additional frequency.

B. Euclidean Distance

In this paper, a calculation of the distance between the video images and the standard image in database is made, from which, the Euclidean distance is obtained. m is assumed to be the current video frame images, and the calculation of the standard template s leads to the formula below:

$$d_{ms} = \sqrt{\sum_{i=1}^{7}(M_i^m - M_i^s)^2} \qquad s\in S \tag{7}$$

V. Motion Sequence Base

The changes in gait are both spatial and temporal. Before they are stored to database as a standard sequence, each of motion sequences is sampled by an exact amount.

A. Represent Body Contour

An important cue in determining underlying motion of a walking figure is the temporal changes in the walker's silhouette shape [8]. The method proposed here provides a simple, real-time, and robust way of detecting contour points on the edge of the target. The centroid (x_c , y_c) of the human blob is determined using the following equations:

$$x_c = \frac{1}{N_b}\sum_{i=1}^{N_b} x_i \qquad y_c = \frac{1}{N_b}\sum_{i=1}^{N_b} y_i \tag{8}$$

Where (x_i , y_i) represents the point on the contour, which there are total of N_b points.

B. Centroid Trajectories

Trajectories of the body contain a lot of information of the moving of pedestrians. The data about the velocities and locations of pedestrian can be received. What deserves to be pointed out is that the information derived from the centroid is important in classification application. The features extracted from the trajectories are periodic, and it is an important component of a movement. The amplitude of the trajectory is related to the size of the person, while the form and symmetry of the trajectory does not depend on it. Displacements of body parts in $x-$ and $y-$direction denote by v_x and v_y respectively. They are derived from two successive formulas:

$$v_x = \frac{x_c^{n+1} - x_c^n}{\Delta t} \qquad v_y = \frac{y_c^{n+1} - y_c^n}{\Delta t} \tag{9}$$

(x_c^n , y_c^n) is the centroid position in the n^{th} frame. Δt denotes the frame rate of the sequence. The features are independent of the sequences at different rates

C. Gait Database

Initialization
{ Find the start frame include the training motion;
Background Subtract; Get the silhouette S_1 ; }
Form a complete sequence of movement
{ i=1; j=2;
Do while i<N % N is the number of motion sample
{

$$d_{s_i s_j} = \sqrt{\sum_{i=1}^{7}(M_i^{s_i} - M_i^{s_j})^2}$$

If $d_{s_i s_j} \prec \sigma$ % σ is the threshold value
j=j+1;
else
$S_{i+1} = S_i$; i=i+1;

Figure 2. *The recursion method*

A set of continuous frames are used to express a cycle of canonical behaviors, distill people's contours, and establish libraries for them. For the establishment of the standard gait base matrix, a learning method for Euclidean distance algorithm is presented. In the stage of training, the recursion method of minimal Euclidean distance is adopted to find the candidate image [31-32]. The method is shown in Figure.2.

The results of eight kinds of gait base are shown in Figure 3, which include walking, uphill and downhill sequences at the speed of $1.5m/s$. All that is stored in the database is the silhouette's seven moment invariants,

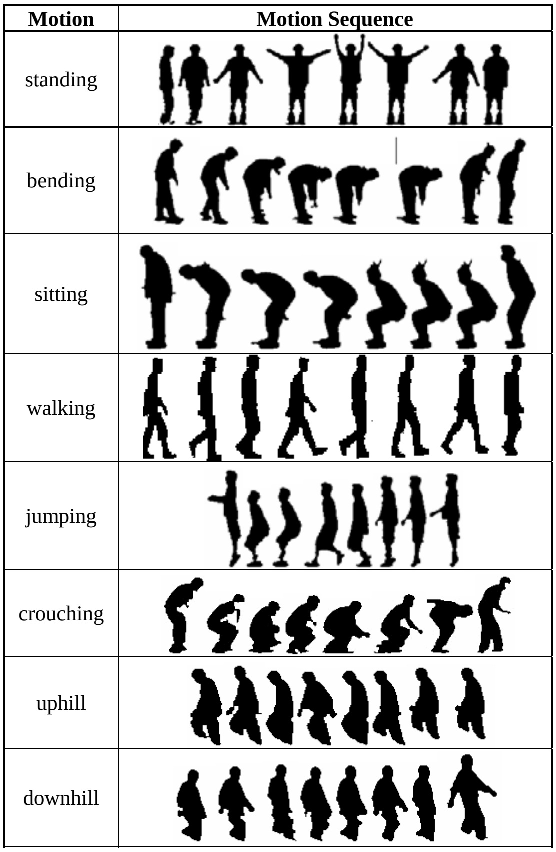

Figure 2. The results of gait base

which reduces computing cost.

VI. Motion Classification

The MID algorithm is applied for the purpose of finding out the similarity of the two silhouette contours. Further, the MSD algorithm for differentiation of motion types is proposed to infer behaviour classification of a walker.

A standard deviation is the numerical value that describes the spread of scores straying from the mean with the same units as the original scores. The wider the spread of scores is, the larger the standard deviation is. A standard deviation is calculated by subtracting the mean of a distribution from the value of each individual variable in the distribution, squaring each resulting difference, summing up all the squared differences, then dividing this sum by the number of variables, and finally taking the square root of this quotient.

The algorithm proposed in this paper is a combination of centroid and the MSD algorithm. The system flow of the proposed gait classification is shown in Figure 4. The human body must firstly be segmented from an image scene for posture classification. Secondly, centroid classification is considered to necessary because of its variation. Finally, the MSD algorithm is adopted for classification [31-33].

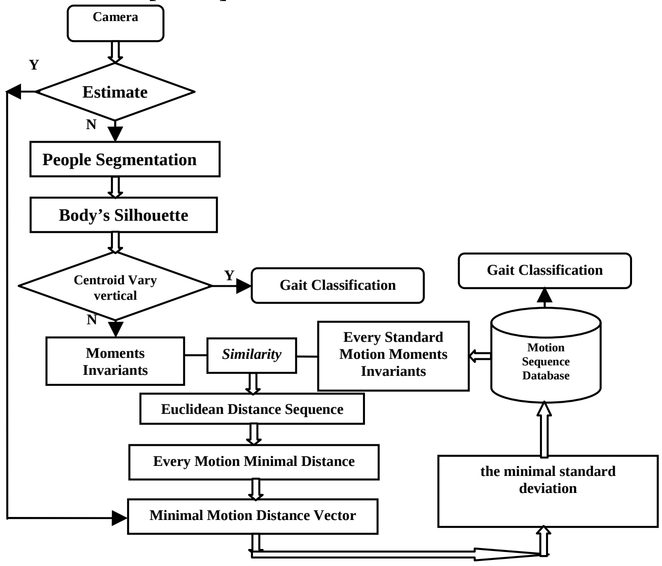

Figure 4. Proposed system flow

In order to ensure the integrality of the contour, the method in Section 3 is used to get the silhouette contour.

In the established coordinate, circular search is conducted to find out the two points which has the maximal abscissa and y-axis and which has the minimal abscissa and y-axis respectively. The line connected with the two points is the rectangle's diagonal, which contains the person's contour. It is also the minimal.

When people enter or leave the scene, the contour is incomplete. To solve the problem, the detection is not performed until targets enter into the scene completely.

Moving human is recognized by silhouette contour, but a problem may arise. For example, when the walker jumps, the pose of body does not make distinctive changes, so it is difficult to distinguish them by the method above. As to its solution, a method is put forward combining the silhouette contour with the centroid trajectories.

The method for classification is as follows:

```
If centroid vertical vary
Then
   If centroid linely ascend
   Then the action is uphill
   Else
       If centroid linely descend
       Then the action is downhill
       Else
           the action is jump
Else
   Use the minimal standard deviation algorithm
```

The vertical centroid is stable. If $v_x \geq 3m/s$, then the movement is classified as running.

Euclidean distance $d_{ms}^{(i)(j)}$ is calculated using Equation (7) whose parameters are the two gait sequences, the incoming image m and the standard image s. i is the number of each motion sequence, which is 1~8 in our method. j is the number of different movements.

The minimal MID is the most similar figure in every motion between the incoming images and the standard images which is numbered from 1 to 8 in the standard library. The minimal distance is calculated as $S[j,k] = \min_{i=1,2\cdots 8}(d_{ms}^{(i)(j)})$, where k is the number of video frame.

The frame is growing in the identification process, and the cease of identification process leads to the frame number N, thus obtaining different motion distance vector $S[j,N]$.

For each kind of movement, the matrix's abscissa standard deviation of MSD is as follows:

$$\sigma_j = \sqrt{\frac{\sum_{k=1}^{N}(S[j,k]-\bar{S}[j,k])^2}{N}} \tag{10}$$

Search the appropriate type of motion in the database according to $\min(\sigma_j)$.

VII. Evaluation and Experimental Results

Two group researches are made here to verify the result of this method for flexible speed movement classification. Standing, lying, bending and sitting are involved in the first group, and walking, side walking, crouching, jumping, uphill and downhill action are involved in the other one. The experiment was carried out on a PC running at 1.7GHz. A speed of about 15 frames per second can be achieved, which is efficient for real-time surveillance. Standing, lying, bending, sitting, walking, side walking, jumping, crouching, uphill and downhill with about 4500 frames are conducted respectively.

The MSD algorithm is tested with over 320 motions at uncertain speed respectively. Each group has 160 motions. The testing data of the recognition are shown in Table I and Table II.

TABLE I.
Testing data Recognition Result

	Standing	Walking	Bending	Sitting	
Standing	36	0	2	2	Average
Walking	0	37	0	1	
Bending	1	3	35	4	
Sitting	3	0	3	33	
Recognition rate (%)	90%	92.5%	87.5%	82.5%	88.13%

From the two tables, it can be seen that the recognition

TABLE II.
Testing data Recognition Result

	Walking	Standing	Jumping	Crouching	Uphill	Downhill
Walking	13	2	1	0	3	3
Standing	1	15	0	1	1	1
Jumping	2	1	14	0	2	3
Crouching	0	0	0	16	1	1
Uphill	2	1	2	2	12	1
Downhill	2	1	3	1	1	11
Recognition rate (%)	65%	75%	70%	80%	60%	55%

rate is different with W^4 [27], which is 86%. Here are the reasons: 1) Table I shows the proposed method has similar correct recognition rate with W^4, as these four movements are very different from silhouette contour. 2) Table II implies that what has been done in posture test is very similar, especially between jumping, uphill and downhill. The pose of a body has not changed significantly, yet the difference is only based on centroid. That is the reason why we have a low recognition rate. 3)In [27], there are only four kinds of gait, including standing, lying, bending and sitting, and their silhouette are quite different. Other test is performed mixing the different types of actions to classify motion, which results in an even lower recognition rate. The purpose of the current method is to identify a single motion.

VIII. CONCLUSION

A description of an approach is given to classify flexible speed using MSD algorithm. According to the method, an IVSS is built. In some scenes, abnormal movements of the pedestrians can be detected and then an alarm will be given to them. Money and manpower would both be saved if that precaution had been taken, and more importantly, crimes can be prevented. Thus, computers can act not only as people's eyes, but also as the assistants that can take in the instructions from people and can describe the actions of mobile targets.

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Hongmin Xue, an Associate professor. He was born in 1970 and graduated from the Mathematics Department of ShaanXi Normal University in July 1990. He received master degree from the School of Computer Science and Technology, Xidian University. Now, he is PhD candidate of computer application technology in Xidian University.

His research works focus on vision computing technologies. The courses he mainly instructs include: Data Structure, Introduction of Software Engineering, and An Introduction to Database Systems.

He has been in charge of, and took part in more than 3 scientific research projects at provincial levels. He has published more than 6 technological papers on internal and external kernel publications, including 2 ones searched by EI compendex, and composed 4 books cooperating with others.

Zhijing Liu, professor and advisor of doctoral students. He was born in April 1957 and graduated from the Department of Computercenter Engineering of Northwestern Telecommunications Engineering Institute in July 1982. He currently serves as head of the Research Center of Computer Information Research Application, and is a director of the China and America Associated Laboratory of key Technologies of Mobile Electronic Commerce.

His research works include: vision computing technologies, network multimedia technologies, technologies of virtual reality, and key technologies of E-government and E-commerce.

He has been in charge of or took part in more than 40 scientific research projects at national, provincial and ministerial levels, and won two National Science and Technology Production Awards. Besides, he obtained eight Science and Technology Production Awards at provincial and ministerial levels. He has published more than 110 technological papers on internal and external kernel publications, including 30 ones searched by SCI, EI and ISTP respectively, and has composed 3 books cooperating with others.

Presently, he acts as member of the Expert Advisory Committee of the leading group of the informatization of Shaanxi province, and is a fellow of the Committee of Experts of manufacturing informatization of Shaanxi province, committeeman of the city of Xi’an’s manufacturing informatization Expert Committee, and appraisal expert of the Committee of Awards of enterprise technology innovation of Shaanxi province.