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A unified face identification and resolution scheme using cloud computing in Internet of Things

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HIGHLIGHTS

- The system model is presented to identify an individual with face identifier.
- Cloud computing-based resolution scheme is proposed.
- We address the problem of cross-industry and cross-platform face identification.
- The parallel resolution mechanism is proposed to improve face resolution efficiency.

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ABSTRACT

In the Internet of Things (IoT), identification and resolution of physical object is crucial for authenticating object's identity, controlling service access, and establishing trust between object and cloud service. With the development of computer vision and pattern recognition technologies, face has been used as a high-security identification and identity authentication method which has been deployed in various applications. Face identification can ensure the consistency between individual in physical-space and his/her identity in cyber-space during the physical–cyber space mapping. However, face is a non-code and unstructured identifier. With the increase of applications in current big data environment, the characteristic of face identification will result in the growing demands for computation power and storage capacity. In this paper, we propose a face identification and resolution scheme based on cloud computing to solve the above problem. The face identification and resolution system model is presented to introduce the processes of face identifier generation and matching. Then, parallel matching mechanism and cloud computing-based resolution framework are proposed to efficiently resolve face image, control personal data access and acquire individual's identity information. It makes full use of the advantages of cloud computing to effectively improve computation power and storage capacity. The experimental result of prototype system indicates that the proposed scheme is practically feasible and can provide efficient face identification and resolution service.

1. Introduction

With the fast development of computing, communication, and control technologies, the fields of IoT and Cyber–Physical Systems (CPS) have attracted much attention in the last few years [1–3]. These technologies realize the interconnection among ubiquitous things by the corresponding applications and services in both physical-space and cyber-space [4–7]. In physical-space, various physical objects (e.g., persons, sensors, computers, mobile devices, and commodity) have been accessed Internet as building blocks of IoT and enable novel applications [8]. Meanwhile, a large number of cyber objects are generated in cyber-space [9,10]. They need to rely on the identification and resolution technology to directly or indirectly communicate and cooperate with each other to reach the goals of information sensing and automatic control [11]. As an important field of IoT, identification and resolution technology has been applied various IoT scenarios. For example, entrance guard, logistics, food safety, supply chain management, Internet Finance (ITFIN), mobile payments, etc. Identification and resolution of physical object has become an important research direction for

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achieving object's identity authentication, data access control, and trust establishment between object and service.

In the process of identification, various physical objects are respectively identified and associated by the corresponding identifiers. So that network and applications can control and manage these objects with identifier to implement information acquisition, processing, access control, transmission and exchange throughout both physical-space and cyber-space. In addition to physical object identification, there are communication identification and application identification. The former is used to identify the network nodes which has the communication ability, for example, IP address, E.164 number. The latter is used to identify the various application services in the application layer, for example, domain name, Uniform Resource Locator (URL). The identity resolution of physical object is a process that maps a physical object identifier to a communication identifier or application identifier or its associated information. For example, by resolving an identifier of product, we can obtain the application identifier which stores its related information or service [12]. The identification and resolution of physical object realize the mutual mapping between the individual in physical-space and the identity information or application service in cyber-space.

For identification and resolution technology, current research mainly concentrates in physical objects with identification (ID) code. Electronic product code (EPC) and ubiquitous ID (uID) are typical ID code [13,14]. They have been widely used in various application areas, including logistics, food safety, supply chain management, commodity retail, and so on. They are accurate identifier which is comprised of numbers or alphabets with certain rules. The Object Name Service (ONS) is a typical resolution model of ID code [15]. It links EPC with its associated Physical Markup Language (PML) data file [16]. The host address on which corresponding PML file is located will be obtained by ONS. However, in some IoT scenarios, there are many objects without any available ID code. We can identify them with their properties, for example, biometric, space–time information, and other characteristics [17–19]. Compared with ID code, these identifiers are not accurate. But they can meet the demands of identification in some IoT applications. Furthermore, they have some of the particular advantages which ID code is not available.

In the future, IoT and Internet of people (IoP) will be interconnected to each other enabled by cloud [20]. More and more people are accessed to the Internet, and corresponding cyber-individuals will be generated [21]. The research on human identification and resolution has become more and more valuable for realizing identity authentication, personal information management and data access control about human.

Face is a discriminative biometric which is used to uniquely distinguish different humans. It is an inherently reliable and distinctive identification method [22,23]. Face identification is a process that analyzes facial images, extracts special useful information such as pixel and position of feature points, size and position of eyes, nose and mouth [24,25]. Finally, face identifier is generated by using the extracted facial feature value. The goal of face resolution is to find the application identifier stored individual's identity information or application service by identity authentication based on face identifier.

Compared with ID code, the process of face identification and resolution is more complex, which result from the characteristics of face identifier. Some algorithms need to be performed, for example, face detection, facial image preprocessing, facial feature extraction and identifier generation, identifier matching. So the computational complexity is greater than that of ID code. Moreover, it needs more storage capacity because the size of face identifier data is relatively larger and data structure is more complex. With the increasing of IoT applications based on face identification, face image database is also growing at the same time. It causes that the time complexity and space complexity of face resolution are further increased. Especially in current big data environment, the demands for computation power and storage capacity will be greater [26,27].

Currently, most of the identification and resolution applications are implemented in the specific and independent IoT scenarios. Simple identification and resolution service model is usually adopted. It is difficult to achieve interoperability between different industries and different platforms. Users need to frequently verify and resolve identity in different applications, which result in inconvenient operation, waste of resource, and increasing risk of privacy disclosure [28]. Furthermore, the future of IoT is moving toward the direction of ubiquity, that is ubiquitous Internet of Things (ubiquitous IoT) [29,30]. It is the integration of multiple independent IoT applications and realizes the interconnections and cooperation among ubiquitous things, as well as pervasive management and access control of IoT resources [31]. This situation facilitates the requirement which design a unified and efficient face identification and resolution scheme to share face services for cross-industry and cross-platform IoT applications.

The advantages of cloud computing technology in providing powerful computational and storage capacity and unified cloud service access can appropriately solve the above mentioned problems [32]. It has many advantages in practical application, which mainly include resource pooling, virtualization, broad network access, high reliability, high scalability, elasticity (dynamic provisioning), service oriented architecture (SOA) [33,34]. These characteristics motivate the utilization of cloud computing technology to store and process face identifier data. Therefore, we design a face identification and resolution scheme based on cloud computing in this paper. This scheme concentrates computation power and storage capacity in cloud platform. It can solve the problems of computation and storage caused by the increasing of applications and users in IoT. Furthermore, we design a parallel resolution mechanism to give full play to the processing capacity of cloud computing and improve the efficiency of face resolution. In this scheme, the face identifier generation model, matching algorithm and service interface are unified. So various cross-industry and cross-platform applications can conveniently access the face identification and resolution service.

In this paper, we focus on identification and resolution based on face, as well as cloud computing-based resolution framework. The main contributions are as follows:

(1) Face identification and resolution system model is presented to implement the face identifier generation and identifier matching. It can effectively identify an individual and realize the identity resolution with face identifier in IoT application.
(2) Cloud computing-based face resolution scheme is proposed to resolve face image, control personal data access and obtain identity information service. It makes full use of the advantages of cloud computing to effectively meet the demands of computation power and storage capacity. Furthermore, it provides a unified face identification and resolution service platform for cross-industry and cross-platform IoT applications.
(3) The parallel resolution mechanism is proposed to improve the efficiency of face resolution.

The remainder of this paper is organized as follows. Section 2 reviews the related work on face identification and resolution. Section 3 presents the face identification and resolution system model. Section 4 proposes the cloud computing-based face resolution scheme. Section 5 presents the experiment and performance evaluation for proposed scheme. Section 6 draws a conclusion.

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2. Related work

The field of identification and resolution of ID code has been researched many years. Identification and resolution based on object's properties becomes more and more concerned. The development of face recognition and computer vision technology greatly promotes the improvement of face identification accuracy. With the increasing number of IoT applications based on face identification, the capacity and efficiency of the process also need to be improved.

Haghighat et al. [35] presented CloudID which is a cloud-based biometric authentication solution with privacy-preserving. The confidential information of users correlated with their biometrics is stored in an encrypted manner. Face recognition is used to make sure that the illegal users cannot obtain any sensitive data. It allows different enterprises to execute biometric authentication on a single database and do not reveal any sensitive information on cloud.

Shu et al. [36] proposed a large-scale face recognition comparison algorithm based on cloud computing. The facial characteristics were extracted by the cloud model. The large-scale facial characteristics comparison was completed by applying cloud computing technique. This method improved face comparison efficiency in large-scale face recognition applications.

Sun et al. [37] proposed a Hadoop platform-based facial image tagging and classifying solution in cloud environment. The powerful computation and distributed processing capability of Hadoop platform was made full use. It can meet the requirements of large face image datasets analysis and complex face image multidimensional structure for solid computing techniques.

Tian et al. [38] proposed and implemented the cloud-based robot platform for real time face recognition system. Cloud computing infrastructure is applied in executing the information process tasks of face recognition. And cloud server could share the information among all the clients of robot application and allowed them to access this platform to obtain service.

In the field of face recognition based on mobile cloud computing, the processing and storage capacity of cloud is used to reduce the computing load of mobile devices. Soyata et al. [39] designed and implemented a face recognition system based on the mobile–cloudlet–cloud architecture (MOCHA). This scheme offloaded the computing load from mobile devices to cloud by performing the task partitioning. The computing tasks were distributed among cloudlets and cloud servers to minimize the response time. Similarly, Bommagani et al. [40] presented a framework about performing face recognition in cloud computing environment. This scheme offloaded a part of recognition tasks to the cloud to ensure that face recognition could be performed on mobile devices. Ayad et al. [41] introduced the Mobile Cloud Computing (MCC) technology and applied it into face recognition. The processing and storage tasks of face recognition were moved from mobile devices to cloud to overcome the mobile applications challenges in processing, storage, and bandwidth.

For multimodal biometrics recognition, Peer et al. [42] applied cloud computing in the area of biometric recognition to solve the problem of scalability, computing power, and storage. By using the accessibility of biometric cloud services, the fusion strategy which combines face and fingerprint into a multi-biometric service were proposed to provide superior recognition performance. Hossain et al. [43] proposed a speech and face recognition framework based on cloud for elderly remote health monitoring. The speech and face image were collected in client and delivered to cloud server to analyze and classify them. The system recognized the elderly patient's state by speech and face features in cloud.

In above research work, some researchers have adopted cloud computing technology to meet the demands for computation power and storage capacity in face recognition. On this foundation, we design the cloud computing-based face identification and resolution system scheme not only meeting the growing demands of computation power and storage capacity, but also providing a unified face identification and resolution service platform for cross-industry and cross-platform IoT applications. Meanwhile, the parallel resolution mechanism is proposed to further improve the efficiency of face resolution.

3. Face identification and resolution system model

In this section, we present the cloud computing-based face identification and resolution system model. We implement the face identifier generation and matching. In our another work, we has presented the face identifier generation algorithm based on Local Binary Patterns (LBP) and face identifier matching algorithm based on Euclidean distance in detail [44]. So we focus on the cloud computing-based system model in this paper.

3.1. Cloud computing-based face identification and resolution system model

The identification and resolution system based on face is the simulation of the mechanism which human's brain distinguishes different individuals relying on face. When the meeting first time, brain can store the facial feature and corresponding identity information into memory. In the next meeting, the brain can authenticate facial features and match them with the templates stored in our memories. Accordingly, humans can recognize each other. Similarly, the face identification is a process that enrolls the identity information of an individual into system and stores his/her face identifier and detailed personal information into database. The face resolution is a process that obtains the identity information of tested individual by comparing with all the face identifiers stored in database.

The face identification and resolution system is similar with the face recognition system. According to the application context, the system mainly includes two phases: face identification and face resolution. Fig. 1 shows the block diagram of face identification and resolution system.

(1) *Face identification*: Face identification realizes the conversion from the face of an individual in physicalspace to the face identifier in cyber-space. It consists of the following function modules: facial image acquisition, face detection, facial image preprocessing, feature extraction and face identifier generation, and system database. In this phase, the facial image of an individual is acquired by vision sensor firstly. The system executes the operations of face detection, image preprocessing, and feature extraction and face identifier generation to be converted into face identifier. Finally, the face identifier and identity information are stored in system database. Usually, multiple face identifier templates of an individual are generated to show facial features all-round from different angles and ensure the accuracy of face identification. Additionally, the face identifiers stored in the system database should be updated over time.

(2) *Face resolution*: Face resolution can realize the mapping from face in physical-space to detailed identity information in cyber-space and feedback from cyber-space to physical-space in an appropriate manner. It consists of the following function modules: facial image acquisition, face detection, facial image preprocessing, feature extraction and face identifier generation, face identifier matching, identity information acquisition, and system database. Some operations are the same for face identification and face resolution. In this phase, the facial image of test individual is acquired firstly. It is also converted into

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face identifier similarly with the face identification phase. Then the generated face identifier is seriatim compared with the enrolled identifiers to authenticate the identity of test individual, namely face identifier matching. If matching successfully, the corresponding identity information of the test individual will be obtained and returned.

In the face identification and resolution system, client is only responsible for capturing facial image, requesting the face identification and resolution service to cloud, and presenting the identity information to users after successful resolution. Most of operations and data storing are performed on cloud. The operations of facial image acquisition, face detection, facial image preprocessing, and feature extraction and face identifier generation are the same in the phases of face identification and face resolution. These functional modules and adopted methods are as follows:

- *Facial image acquisition*: This module is responsible for capturing facial image of an individual using camera. It is located in local client.
- *Face detection*: For a raw facial image, only the face region is useful for face identification and resolution. Other regions are useless and may have a negative impact on face resolution. So they should be removed. In this paper, Haar face detection method contained in OpenCV is applied to extract the face region [45].
- *Facial image preprocessing*: The quality of raw facial image is usually influenced by various factors, for example, illumination, posture, camera pixels, and so on. Some image preprocessing operations need to be executed to enhance facial image. In this paper, graying color face image algorithm and histogram equalization algorithm are performed to enhance the facial feature and eliminate effects of these adverse factors.
- *Feature extraction and face identifier generation*: This module is responsible for extracting the facial feature value by face feature extraction algorithms. The extracted feature value is used to generate face identifier, which serves as the "ID code" of the individual.
- *Face identifier matching*: In this module, the extracted face identifier is seriatim compared with all the enrolled face identifiers stored in system database to found out the most similar one. Then the similarity needs to be compared with the threshold to determine whether the match is successful. According to the matching results, corresponding decision is made, which include two results: identity is confirmed or unidentified. In database, the face identifier is stored together with the URI address of corresponding identity information in the form of two-tuples. When matched successfully, the corresponding URI address will be returned.
- *Identity information acquisition*: This module is responsible for managing the identity information of enrolled individuals. It is also responsible for retrieving identity information according to the URI address obtained by identifier matching.
- *System database*: The facial identifiers and identity information of registered users are stored in the system database. The powerful storage capacity of cloud computing can fully meet the demands of system.

3.2. LBP-based face identifier generation

The process of face identifier generation refers to transform the face in physical-space into identifier in cyber-space to identify the identity of an individual. The face identifier is composed of facial feature value. So its core is facial feature extraction.

There are many face feature extraction algorithms in the field of computer vision. They represent facial features from different angle by analyzing face image. The quality and representation ability of identifier can influence the accuracy rate of face classification and resolution. Its size can directly influence the amount of database storage.

In our previous work, the face identifier generation model based on uniform Local Binary Patterns (LBP) has been presented in detail [44]. It uses the uniform LBP algorithm to extract facial feature [46,47]. And the extracted facial feature vector is used as the face identifier. This paper still adopts this identifier generation model.

The uniform LBP is the improvement and optimization of original LBP [48]. It ameliorates the situation that feature histogram of original LBP is too sparse. It greatly reduces the size of face identifier by dimensionality reduction. In addition, it has the characteristic of rotation invariance and gray scale invariance and has high discrimination for different facial images. So the uniform LBP feature is very suitable for using as face identifier.

In our scheme, we do not restrict the use of any facial feature extraction algorithm. In addition to LBP algorithm, other facial feature extraction algorithms can also be used in our face identifier generation model.

3.3. Euclidean distance-based face identifier matching

Face identifier is different from ID code which is an accurate identifier. The matching process needs to calculate the similarity as the matching basis. In our previous work, the Euclidean distance-based face identifier matching algorithm has been presented in detail [44]. In this paper, we still use this algorithm to seriatim calculate the similarity between the face identifier of test individual and each of enrolled face identifiers. By this way, we can find the most-likely candidate which has the smallest distance. Then we compare the smallest distance with the threshold. If it is less than the threshold, the matching is successful. Otherwise, it is a failure.

In this section, we have presented the face identification and resolution system model based on cloud computing. The functional modules of face identification and resolution system are presented, and the adopted algorithms of each module are introduced. This system model implements the mutual mapping between an individual in physical-space and the identity information in cyber-space.

4. Cloud computing-based face resolution scheme

In this section, we introduce the cloud computing-based face resolution framework. Because the operations in face identification phase need also to be performed in resolution process, we only focus on the process of face resolution here. The core of face resolution is the face identifiers matching. We present a parallel matching strategy to improve the efficiency of face resolution.

4.1. Parallel face identifier matching

For face resolution, the demand for computation and storage resource will be increasing as the size of face identifiers database grows. The overall response time of resolution operations can be greatly reduced by parallel processing mechanism. The parallelization refers to breaking face identifiers database, and a plurality of processing units synchronously performs face resolution operations. Each processing unit just executes identifier matching with a subset of face identifiers database.

In a resolution process, we assume that there are N enrolled face identifiers set $\boldsymbol{V}'$ in database. For a given facial image F of test individual, the extracted face identifier $\boldsymbol{V}$ needs to seriatim match with the N enrolled face identifiers according to the

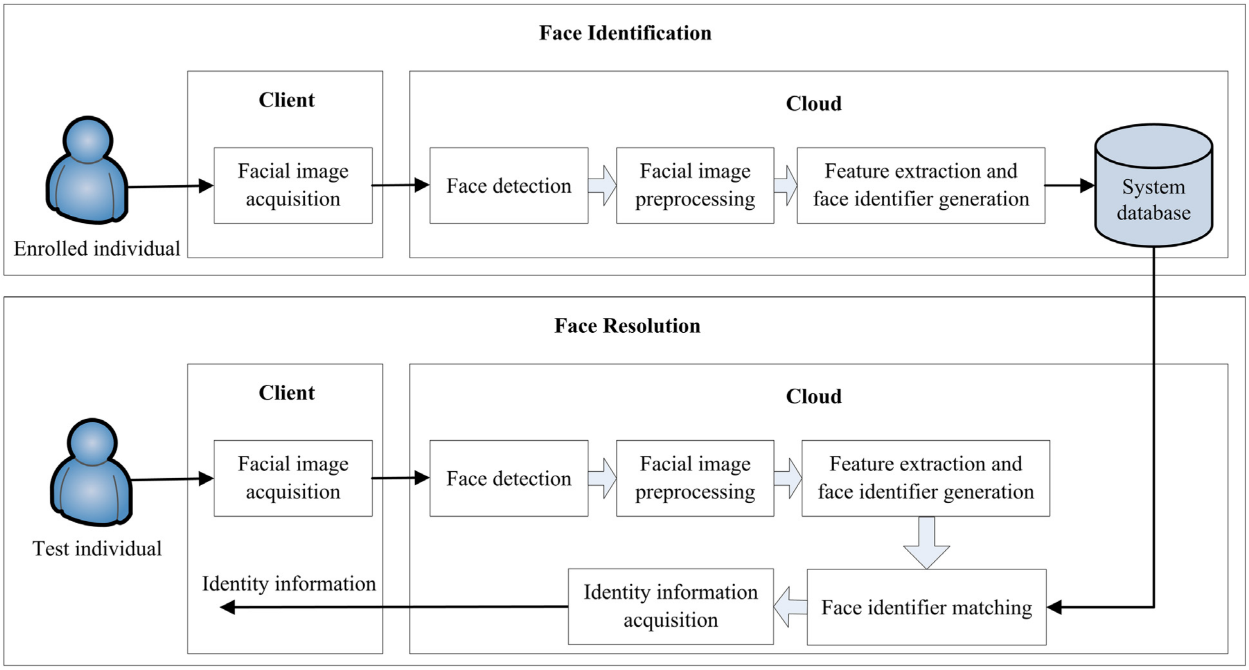

Fig. 1. Block diagram of cloud computing-based face identification and resolution system model.

matching algorithm based on Euclidean distance. We define k as the number of resolution processing units. Meanwhile, we divide the N enrolled face identifiers into k resolution processing units. For the ith processing unit p_i, where $i = 1, 2, \ldots, k$, there are x_i enrolled face identifiers that needs to be matched. In this paper, we set the number of each group enrolled face identifiers for all the processing units as equal as possible. That is to say $x = x_i$ for $i = 1, 2, \ldots, k$. So it can be calculated that $N = kx$.

For each test face identifier, the k processing units can implement resolution operations in parallel and independently. Each processing unit p_i can get a candidate individual c_i which the Euclidean distance is the smallest for all the x_i enrolled identifiers. All the k resolution processing units can get a candidate set $C = \{c_1, c_2, \ldots, c_k\}$. Finally, we can find the most-likely candidate which the distance is the smallest in candidate set C. If the smallest distance is less than the threshold T which is set in specific scenario, this most-likely candidate is the individual that we want to find. Otherwise, the face matching is a failure. The detailed parallel face identifier matching algorithm is shown in Algorithm 1.

Compared with the traditional non-parallel method, this method can reduce the number of matched face identifiers to $1/k$ for each processing unit. It can greatly improve the efficiency of face resolution.

4.2. Cloud computing-based face resolution framework

In this paper, we design a cloud computing-based face resolution framework to meet the demands of computation power and storage capacity, and provide a unified face resolution scheme for cross-industry and cross-platform applications. In this scheme, resolution services and identity information management services are deployed in the cloud which can make full use of the high reliability, high scalability, powerful computing and storage capacity of cloud computing to provide efficient and accurate face resolution services for various applications. These functional modules presented in Section 3, namely facial image acquisition, face detection, facial image preprocessing, feature extraction and face identifier generation, face identifier matching, identity information acquisition, and system database, are deployed in client and cloud to complete the face resolution task collaboratively. Fig. 2 shows the cloud computing-based face resolution framework.

This face resolution framework consists of six parts: vision sensor, client, management server (MS), resolution server (RS), information server (IS) and data center. Among them, MS, RS, IS and data center are deployed in cloud. The functions of each module are as follows:

- *Vision sensor*: It is responsible for capturing facial image. Normally, high articulation cameras are adopted. In some cases, vision sensors are directly embedded into client, e.g., mobile phone, PDA, attendance equipment based on face, etc.
- *Client*: Client is responsible for managing sensor devices and requesting the face resolution service to cloud. Besides, it will present the resolution results to users after successful resolution. Client is usually composed of computer, mobile phone or terminal device with camera. In our framework, client is only responsible for very little and simple work and needs very little computation power. So the client is lightweight in our scheme, which can especially be applicable to the resolution situation that the computation power of client is relatively weak.
- *MS*: MS is responsible for managing various resources in cloud. It connects with client, RS and IS. It provides the unified and standard resolution service interface which can be accessed by various cross-industry and cross-platform IoT applications. When receiving resolution request and face image, MS will transmit it to RS to request the face identifier generation and matching services. After matching successfully, MS will request the corresponding identity information services to IS. Finally, it will return the resolution results to client.
- *RS*: RS is responsible for performing face detection, facial image preprocessing, feature extraction and face identifier generation, and face identifier matching. The face identifier generation model and identifier matching algorithm presented in above section are all performed in RS. When matching is successful, the URI address of corresponding identity information or personalized services will be returned. So it inputs face image

Algorithm 1. Parallel Face Identifier Matching

Input:
Face identifier of test individual, $\boldsymbol{V}$;
The set of enrolled face identifiers, $\boldsymbol{V'}$;
Similarity threshold, T

Output:
The successfully matched individual c

N enrolled face identifiers set $\boldsymbol{V'}$ are split into k parts, namely $\boldsymbol{V'}_1, \boldsymbol{V'}_2, \cdots, \boldsymbol{V'}_k$
Send $\boldsymbol{V'}_i$ to processing unit p_i
$j \leftarrow 2$
The minimum Euclidean distance between $\boldsymbol{V}$ and subset $\boldsymbol{V'}_i$ $subset\_min\_distance_i \leftarrow$ The Euclidean distance $d_i[1]$ between $\boldsymbol{V}$ and $\boldsymbol{V'}_i[1]$
The number of the face identifier with minimum Euclidean distance in subset $\boldsymbol{V'}_i$ $subset\_min\_distance\_No_i \leftarrow 1$
while $j \leqslant x_i$ **do**
  $d_i[j] \leftarrow$ The Euclidean distance between $\boldsymbol{V}$ and $\boldsymbol{V'}_i[j]$
  if $d_i[j] < subset\_min\_distance_i$ **then**
    $subset\_min\_distance_i \leftarrow d_i[j]$
    $subset\_min\_distance\_No_i \leftarrow j$
  end if
  j ++
end while
Similarly, other k-1 resolution processing units also perform above steps simultaneously. Finally, all the candidate individual $c_i[subset\_min\_distance\_No_i]$ are put into candidate set C
$r \leftarrow 2$
The minimum Euclidean distance in candidate set C $min\_distance \leftarrow d_1[subset\_min\_distance\_No_1]$
The number of the face identifier with minimum Euclidean distance in candidate set C $min\_distance\_No \leftarrow 1$
while $r \leqslant k$ **do**
  if $d_r[subset\_min\_distance\_No_r] < min\_distance$ **then**
    $min\_distance \leftarrow d_r[subset\_min\_distance\_No_r]$
    $min\_distance\_No \leftarrow r$
  end if
  r ++
end while
if $d_{min\_distance\_No}[subset\_min\_distance\_No_{min\_distance\_No}] < T$ **then**
  return $c_{min\_distance\_No}[subset\_min\_distance\_No_{min\_distance\_No}]$
else
  return The face matching is a failure
end if

and outputs URI address. RS is deployed in the manner of server cluster to give full play to the parallelism and provide powerful computational capability. Multiple processing units perform face resolution task in parallel according to the method presented in above section.

- *IS*: IS is responsible for managing identity information and providing identity information services for users and various applications. In different scenarios, the form of information service is various, for example, returning identity profile, providing specific application interface, and so on. IS can be deployed and changed conveniently according to different application requirements in this architecture.
- *Data center*: Data center has powerful data storage capability. It stores and manages face identifier data, URI addresses of IS on which identity information or corresponding service resource is located, and identity data of individuals.

All these functional modules cooperate with each other to complete the face resolution task. The detailed procedure of face resolution is shown in Algorithm 2.

In the above resolution scheme, the cloud computing-based face resolution framework is presented to realize fast, accurate and efficient face resolution service, and provide support for identity authentication, personal information management and data access control about human. MS, RS, and IS are separately deployed, which can improve flexibility of framework. In addition, the resolution process is provided in the form of cloud service, and provides stander service interface. And the face identifier generation model and matching algorithm are also unified. So various cross-industry and cross-platform applications can conveniently access and obtain the identification and resolution service based on face identifier.

5. Experiment and performance evaluation

In this section, we implement a prototype system to demonstrate the practical feasibility of cloud computing-based face identification and resolution scheme proposed above. The experimental results are presented and the performance of scheme is evaluated and discussed from multiple aspects.

5.1. Experimental setup

Our experimental environment consists of client and cloud server. The cloud server is hired from an operator. It is equipped with Intel Xeon CPU 2.80 GHz, 8-core, 8 GB memory, and running Windows Server 2008 OS. Client applies a laptop equipped with Intel Core i5-4200U CPU 2.60 GHz, 2-core, 4 GB memory, and running Windows 7 OS. The development platform is Microsoft Visual Studio 2010. OpenCV libraries are used in developing the algorithms of face detection, facial image preprocessing, face identifier generation, and face identifier matching. Microsoft SQL Server 2008 database is used as system database to store face identifiers and identity information.

In this experimental environment, MS, RS and IS programs are deployed on the cloud server. We use different CPU threads to run

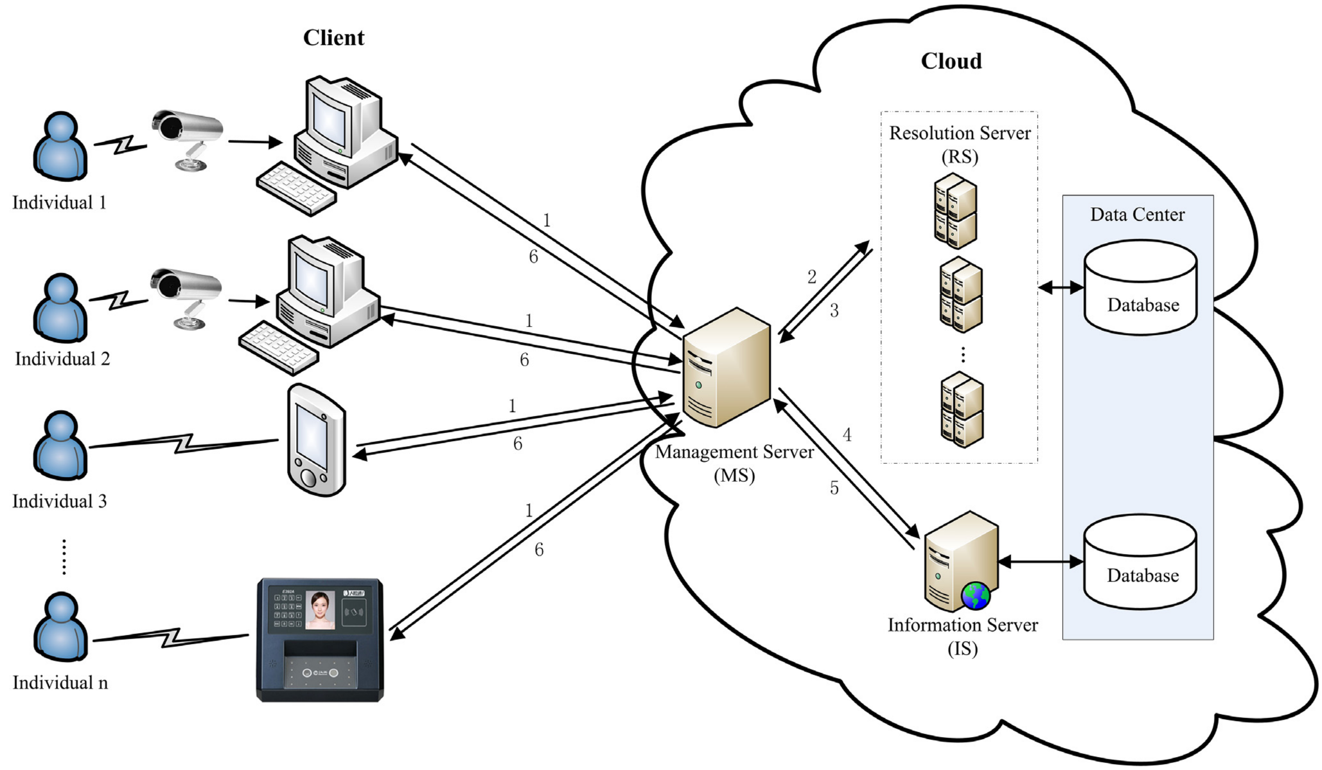

Fig. 2. The cloud computing-based face resolution framework.

Algorithm 2. The procedure of face resolution

Begin
Step 1. Client requests the face resolution service.
Step 1.1. Camera acquires facial image of individual, and sends the raw facial image to client.
Step 1.2. Client requests the face resolution service to cloud server and establishes network connection.
Step 1.3. Client sends raw facial image to MS in cloud.
Step 2. MS receive the raw facial image and send it to RS to execute identity resolution.
Step 3. RS receive the raw facial image and implement face resolution.
Step 3.1. The algorithms of face detection, facial image preprocessing, feature extraction and face identifier generation are performed to generate the face identifier firstly.
Step 3.2. The generated identifier is seriatim compared with the enrolled identifiers by performing face identifier matching algorithm. After successful matching, the URI address of corresponding identity information, which is paired with the face identifier matched successfully, will be obtained.
Step 3.3. RS returns the URI address to MS.
Step 4. MS receive the URI address and establish connection with IS by it. MS request the identity information acquisition service to IS.
Step 5. IS acquire the detailed identity information about the individual by the URI address, and return it to MS in specific way, for example, PML document, web service, data file, and so on.
Step 6. MS return the detailed identity information of the individual to client, and then display it to end users.
End

these functional modules to simplify the experiment processes. Data transmission use Http protocol. The overall prototype system is deployed according to the framework proposed in Fig. 2. The uniform LBP-based face identifier generation model and Euclidean distance-based face identifier matching algorithm are adopted.

In the experiment, the Caltech face database, the Georgia Tech (GT) face database, the BioID face database and the ORL face database are applied as the test face database. They are all public face database. The Caltech face database is composed of 450 color face images of 27 people. The pixel of each image is 896×592. For this face database, 1 image of each person is chosen randomly as the test set, and others as training set. The GT face database is composed of 50 people. All people are represented by 15 color JPEG images with cluttered background. These images have not been processed. The pixel of each image is 640×480. For this face database, 14 images of each people are chosen randomly as the training set, and the remaining 1 image as test set. The BioID face database consists of 1521 gray level images of 23 people. The pixel of each image is 384×286. For this face database, 2 images of each person are chosen randomly as the test set, and others as training set. The ORL face database is composed of 10 different images of each of 40 people. The pixel of each image is 92×112. For this face database, 9 images of each person are chosen randomly as the training set, and the remaining 1 image as test set.

The four face databases are respectively tested. We firstly execute the face identification for training set, and enroll their face identifiers and identity information into system database. Then the

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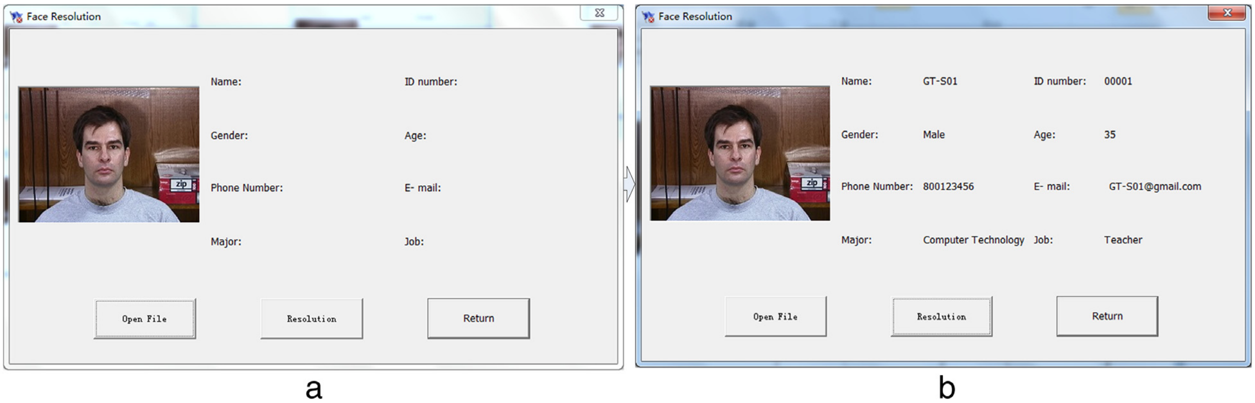

Fig. 3. An example of resolution result: (a) requesting cloud resolution service; (b) the result of face resolution.

test set is used to execute face resolution to verify the performance of the scheme proposed in this paper.

5.2. Experimental results and performance analysis

The face resolution result can be presented in many forms, which are decided by application scenario and the form of information service. We take the form of simple identity profile as an example in our experiment. A test facial image of GT face database is input into client to request cloud resolution service. Cloud server performs face resolution and returns the resolution result. The resolution result is shown in Fig. 3.

In our experiment, we compare our scheme with the original LBP-based cloud resolution model to test and evaluate the performance of proposed scheme. The characteristic of two resolution models in our prototype system are as following: (1) Original LBP-based cloud resolution model: the identifier generation model adopts original LBP feature extraction algorithm. The size of face identifier is not reduced dimension. The cloud computing-based resolution framework presented in Fig. 2 is applied; (2) Our scheme: namely the uniform LBP-based cloud resolution model, the identifier generation model adopts uniform LBP feature. The size of face identifier is greatly reduced by dimensionality reduction. The cloud computing-based resolution framework presented in Fig. 2 is applied. For the two resolution models, four test sets are respectively performed resolution service. The average value of statistical results is used as the measurement criteria of performance. We have measured the following performance indexes:

(1) *Response time for different face databases*: The time consumption from requesting resolution service to receiving resolution result in client is recorded as system response time. The response time using different resolution models in four face databases is shown in Fig. 4. We can find that our resolution scheme can effectively reduce the overall response time in different face databases. Meanwhile, the sequence of response time is Caltech > GT > BioID > ORL for two resolution models. The reason is that the pixel value of face image in four face databases is Caltech > GT > BioID > ORL. The higher the pixel value is, the longer the network transmission latency is. That is to say the response time has a great relationship with the pixel value of face image. Therefore, in the case of not reducing the resolution accuracy, we can reduce the resolution time by reducing the pixel value of face image as far as possible in practical application.

(2) *Resolution rate for different face databases*: For the proposed scheme, the accuracy rate of resolution is directly influenced by the face identifier generation model and face identifier matching algorithm. We adopt different face identifier generation model and same face identifier matching algorithm for two resolution models. Their resolution rates are the same for the same face database. The detailed results are shown in Fig. 5, namely 92.31% for Caltech, 90% for GT, 96.77% for BioID, and 95% for ORL. The result shows that the two models have good resolution accuracy. In addition, this also indicates that the advantages of our scheme are presented in the premise of not decreasing the resolution accuracy rate.

(3) *Response time for different size of face database*: We take the BioID face database as an example to store different number of face images each time in database. The response time for different size of face database is shown in Fig. 6. We can see that the response time increases along with the growing of face database for two resolution models. But our scheme is always lower than the original LBP-based cloud resolution model. And the increment speed of our scheme is slower. This indicates that our scheme has stably advantages and can meet the demands of computation power and storage capacity.

(4) *Matching time using parallel process mechanism*: For evaluating the performance of proposed parallel face identifier matching mechanism, we set different number of resolution severs (RSs) to perform face identifier matching in GT face database. To simplify experiment, we use different CPU threads to emulate multiple RSs. The matching time using different number of RS threads for two resolution models is shown in Fig. 7. The result indicates that the proposed parallel matching mechanism can greatly improve the resolution efficiency. Because the dimension of identifier for our scheme is smaller than original LBP-based cloud resolution model, the computational complexity of identifier matching is relatively lower. So the matching time of our scheme is always less. However, the matching time is not exponentially reduced but slowly after reaching a certain value. That is because not all resolution operations are parallel and there is communication cost between computational element and storage element. It also indicates that the number of RSs cannot be increased illimitably. In any case, parallelism and computation capacity of cloud computing greatly improve the performance of face resolution system.

5.3. Discussion

The above is quantitative analysis for the performance of proposed scheme. It has some other advantages. We expound them from the following aspects.

(1) *Lightweight client*: In our resolution scheme, client is only responsible for very little and simple work, for example, managing visual sensors, requesting the face resolution

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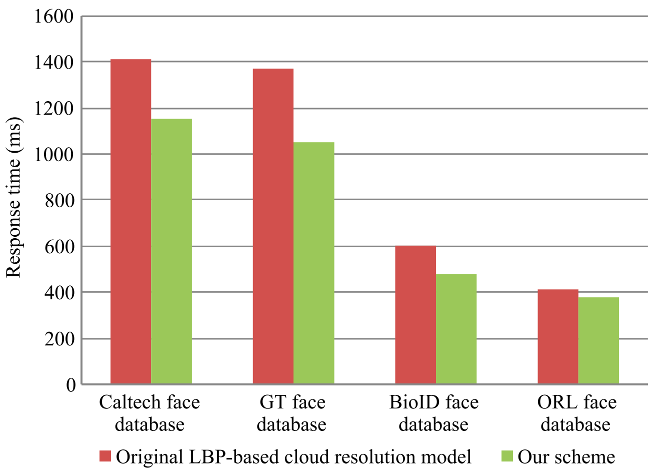

Fig. 4. Response time for different face databases.

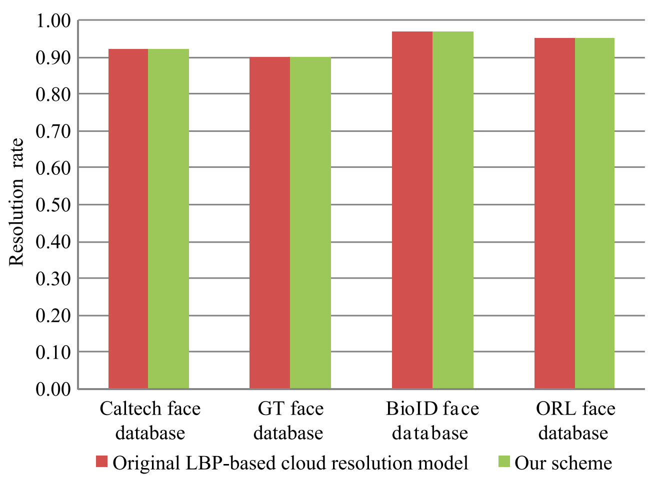

Fig. 5. Resolution rate for different face databases.

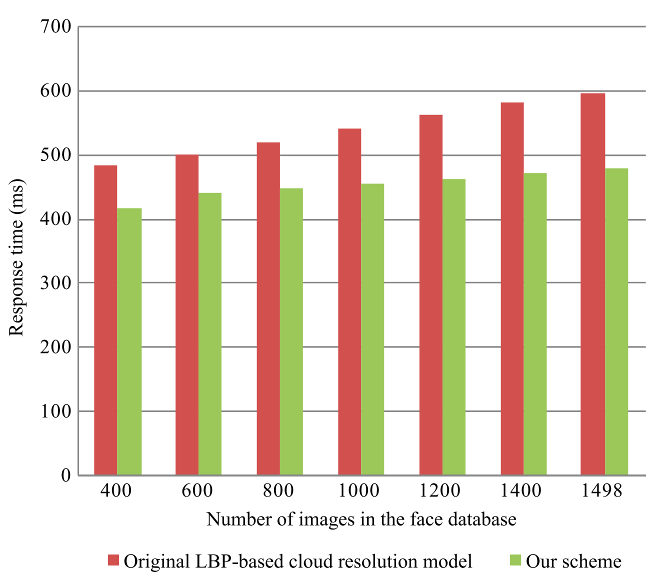

Fig. 6. Response time for different size of face database.

service, and presenting returned resolution result to user. It only needs very little computation power. So this scheme can especially be applicable to the resolution situation that the computation power of client is relatively weak.

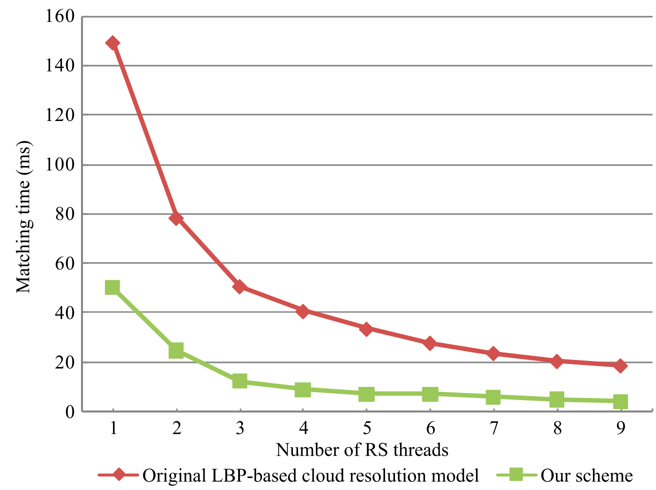

Fig. 7. Matching time using multi-RS threads.

(2) *Cross-industry and cross-platform resolution service*: For the scheme proposed in this paper, the face identification and resolution is provided in the form of cloud services, and standard service interfaces are provided. Meanwhile, the face identifier generation model and matching algorithm are also unified. So various cross-industry and cross-platform IoT applications can easily obtain the face resolution service and share data service from the unified face identification and resolution platform.

(3) *Simplicity of deployment and access*: Cloud computing-based face resolution architecture is simple and easy to be deployed. The most operations are deployed on cloud server, and the client is only responsible for little and simple operations. Moreover, the face identification and resolution is provided in the form of cloud services, and various applications can conveniently access cloud identification and resolution platform.

(4) *Low cost of updating*: Along with the development of face recognition and computer vision technology, high efficiency and accuracy facial feature extraction and facial identifier matching algorithms will emerge. The resolution scheme needs to be updated regularly to improve the resolution accuracy and optimize performance. For cloud computing-based face identification and resolution scheme, the updating work can be implemented simply and conveniently because most the resolution operations are located in the cloud. The client does not need to make any changes. In this way, the cost of updating is greatly reduced.

(5) *Commonality of resolution framework*: In this paper, we have only presented the scenarios of identification and resolution based on face. Other biometrics are also applicable, because the processes of identification and resolution for most biometrics are very similar. Only the raw data collection manner, biometric identifier generation model, and identifier matching algorithm need to be replaced. This resolution framework has a good commonality.

From the above experiment results and performance analysis, the cloud computing-based face identification and resolution scheme can meet the demands of computation power and storage capacity. It can provide effective resolution service for various IoT applications based on face identification.

6. Conclusion and future work

In this paper, we have proposed a cloud computing-based face identification and resolution scheme for IoT applications to

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implement high-security identification, identity authentication, personal information management, and data access control about human. Face in physical-space is converted into face identifier in cyber-space, which is used as a reliable identification technology for human. The constituent parts and workflow of face identification and resolution system model have been presented to realize face identifier generation and matching. The cloud computing-based face resolution framework has been designed. It makes full use of the advantages of cloud computing to effectively meet the growing demands of computation power and storage capacity in current big data era. Meanwhile, the parallel resolution mechanism has been presented to improve the efficiency of face resolution. In our scheme, the face identifier generation model and matching algorithm and service interface are unified. So it can provide a unified face identification and resolution service platform for cross-industry and cross-platform IoT applications. The experimental results of prototype system indicate that the proposed scheme is practically feasible and able to meet the requirements for computation and storage capacity.

Although the proposed scheme has many advantages, there are still some works which need to be explored in the future research. For example, (1) Privacy and security issues: biometric information is usually related to personal privacy, so the identification and resolution system should provide secure and reliable privacy protection mechanism. Especially in cloud computing environment, this issue should be paid more attention because face feature data is stored in third-party data centers; (2) Update mechanism of face identifier templates: although the face features have strong stability, some factors can still cause the changes of feature in practical applications, e.g., disease, aging, injury, weight increase or decrease. The performance of face identification will fall, if the face identifier templates are not updated periodically; (3) The power consumption problem: In the field of IoT and cloud computing, the power consumption is a significant performance index. Our scheme should reduce energy consumption as much as possible while providing efficient service. Research on face identification and resolution has important academic and practical value, and needs further in-depth study.

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