Ant System based Flexible and Cost Effective Routing for Wireless Face Recognition

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***Abstract*—Biometrics can be applied in existing systems for authentication with security, speed and ease of use. A wireless network is very suitable to incorporate biometrics into existing systems, and the integration requires reliable and efficient data routing within the system. Ant System is proposed to establish an adaptive route for data transmission among distributed nodes whilst maintaining the required bit error rate under varying channel conditions and consuming minimal energy. Face recognition is implemented in simulation to test the robustness and energy consumption of the biometric system within a wireless framework, and the results show that Ant System based routing is efficient and as robust as a wired system, and there is no extra hardware needed to implement the routing.**

I. Introduction

Biometrics are used to authenticate a claimed identity, or detect a potential identity of interest in surveillance. Biometrics can be integrated with existing systems to enhance system security with speed and ease of use. A wireless sensor network is very suitable for the integration, because a wireless setup incurs minimal modification to existing systems, a wireless sensor network provides scalable and flexible monitoring region, and if a new wireless network has been set up, once the security level changes and the network needs to be moved, the wireless network can be moved and reused easily. However, in a wireless network, the transmission channel is not as stable as in a wired network. Transmission errors occur due to fading, etc. Meanwhile, the sensor nodes may not be recharged easily, such as in unattended areas or battlefields. Scavenging [1] is an efficient way to harness the ambient energy around the sensor nodes to prolong the battery life, and a reliable and efficient routing protocol is the solution to prolong the sensor network life. Because of the simplicity and low cost of sensor nodes, it is desirable that the routing protocol does not require complex calculation at the nodes. Ant System provides exactly such a solution. Ant System is based on Swarm Intelligence [2], where simple ant agents interact collaboratively to accomplish a complex task. Ant System optimizes the network transmission constrained by power, distance and noise, etc.

Typical issues related to a wireless network are energy conservation, stability, convergence of the routing algorithm [3], scalability, Quality of Service (QoS), real time adaptation, and reliability [4]. The routing algorithm must optimize performance parameters that characterize these wireless qualities while monitoring the state of the communication links among sensors. The performance parameters considered in this paper are hops, distance, energy and transmission error. In light of making the routing protocol general for different biometric systems and different sets of features, a lower level error measure, bit error rate, is considered. A higher level error measure, such as identification error rate, may be implemented in the future, but it needs to be customized for different biometric systems, and different feature extractions, which is not as general as bit error rate. Transmission error is a key issue affecting the accuracy, which is vital to the operation of wireless biometric sensor network [5]. Security strengthening of the system itself is also important to combat malicious attacks [6].

Except for transmission within the network, communication delays and sensor failure also requires attention. In order to manage all these issues efficiently in an integrated manner, we utilize Ant System to construct the routing protocol. The Ant System [7], developed from Swarm Intelligence, is a learning algorithm that uses local information interactively to reach a global optimum by a group of agents. Ant agents sense the network link and update the link status collaboratively, thus enabling the robustness of a network in a decentralized manner. The optimization of routing within a network is shown to be a Nondeterministic Polynomial (NP) hard problem [8], and traditional optimization, such as Newton descent method, can not solve this problem efficiently. The manner of local interaction gives Ant System robustness and versatility to solve this NP hard problem. Ant System enables the wireless sensor network to self organize and optimize sensor activity. A sensor network with these capabilities can efficiently route, predict and self-heal [9]. Data routing is based on the sensors' capabilities and energy capacities, which are especially needed in unattended deployment.

Face recognition is implemented as a biometric example in this paper. A face recognition system analyzes face images, extracting features and classifying the testing images. In face recognition, the data are images or transformed coefficients. Accurate and efficient data transmission is crucial in fulfilling this task. For recognition purpose, a part of the face image contains more prominent features than other peripheral regions of the face image; or, a part of the coefficients are more influential in image reconstruction and recognition than other coefficients. Therefore, the importance of the data should be incorporated into the routing protocol to allocate limited network resources efficiently. Different importance of data happens not only in face recognition, but also in other biometrics, such as fingerprint and iris recognition. In fingerprint recognition, minutiae are more important than other curvatures. In iris recognition, the pattern that is used to register the pupil boundary is crucial and of great importance. Therefore, in this paper the routing protocol is designed without specifying the data nature, but only with prioritization of the data. Hence, this routing protocol can be readily generalized in other biometric applications. The suitability of Ant System in wireless data transmission protocol is due to its discrete nature, fast convergence and reachability to global optima, comparing with Genetic Algorithms (GA) [10], Simulated Annealing (SA) [11], etc. Therefore, Ant System is utilized to construct an efficient and accurate data routing scheme.

The rest of this paper is organized as follows. Section II provides a system description of wireless face recognition and defines the important parameters for wireless face recognition. Section III justifies the usage of Ant System and discusses its performance on a sensor network. Section IV provides simulation results to illustrate the effective routing of prioritized data and the final accuracy of the face recognition system. Section V concludes this paper with future work.

II. System Description of Wireless Face Recognition

Face recognition, as a secure verification method, has been gradually accepted by the general public, not in scientific fictions, but in reality. Face recognition does not require the user to touch anything, as in fingerprint recognition, or assume a special pose as gazing into the iris scanner in iris recognition. Using face recognition is a more pleasant experience for the user than other biometrics. Face recognition is an important biometric in security system for its speed, non-contacting property and improved accuracy. Wirelessly constructed face recognition system is more flexible in watching the dynamic region of interest, in the specific deployment of cameras and in sharing the face database. In wired face recognition system, the data transmission is usually reliable, and the goal of a successful wireless face recognition system is to keep up with the performance of a wired system while enjoying the convenience of a wireless system. What's more, being integrated into a wireless network, face recognition enhances the functionality of the existing wireless network. For instance, Zaeri, Mokhtarian and Cherri discuss face recognition for wireless surveillance systems [12]. Ikdong, Jaechang, Jason and Wayne implement a wireless face recognition system based on ZigBee with low power consumption [13].

Face recognition includes verification and identification. Face verification is one-to-one matching, which is relatively simple, and it has been realized in mobile phone or computer login verification by Omron, Oki Electric, FaceCode, etc. Face identification is one-to-many matching, which is more complex, since a huge database needs to be compared, and *curse of dimensionality* phenomenon happens. The common procedure of face recognition includes enrollment and recognition. In enrollment, the images of the registered users are processed into templates by the specific algorithms, and these templates are stored. The processing techniques and the templates are adjusted concurrently. In recognition, the face recognition system receives a new image, transforms and stores the new image by the same algorithm, and compares it with the templates. The decision process may incorporate all kinds of classifiers. If the classifier is a learning algorithm requiring training such as the neural network or Bayesian network, the training database may be split to learn the classifier structure and construct the templates. The decision can be acceptance or refusal of the testing image with an identity. If the user is accepted and the impostor is rejected, then it is a correct decision; otherwise it is an incorrect decision.

As the security situation varies, an intelligent, wireless biometric security system can adapt to the new needs due to dynamic environment and sensor status. The face recognition system can quickly expand by adding cameras near the region of interest and connecting to the existing network by wireless channels. Our goal is to make the wireless face recognition system as nearly robust as a wired one.

Data, either the full image or representative coefficients, need to be transmitted with high fidelity to the remote processing center, where the face recognition database is stored. An image compression based transformation helps improve data transmission efficiency, such as by discrete wavelet transform or contourlet transform [14]. Transmitting coefficients reduces the data rate significantly allowing us to add extra error correction and data verification increasing system robustness. Our former work [15] shows that the wavelet or contourlet transforms can be made robust to transmission loss.

The routing of data starts from source nodes, the imaging sensors, to destination nodes, the processing unit and database, by a wireless sensor network. The sensors within the network can be active or idle depending on its energy capacity and whether the previous route is passing them. While the ant agents are forming the routes, there are usually multiple choices, and then the ant agents pick the most efficient route to the destination using fewer bits, less energy consumption and less transmission error. The data collected at the destination is processed, and a decision is made. Ant System based routing is a cross layer design, where the conditions of the physical layer and the MAC layer are considered together to efficiently allocate the network resources.

Another reason to transmit transform coefficients is that the coefficients assist fast processing in application layer. A coarser, lower resolution image is produced at the higher level of Laplacian Pyramid, to identify and locate the person with fewer computational and transmission resources. Once the face recognition system determines that there's a possible identification, it requests more detailing coefficients from the sensor and processes the images with higher resolution. Bandwidth requirements gradually increase from coarse scale to fine scale. Meanwhile, the detailing coefficients are usually small and dense near zero. Entropy coding is efficient in representing the face coefficients, improving transmission efficiency by reducing energy consumption, and reducing transmission error. In the next section, an efficient routing scheme is discussed.

III. Ant System based Routing

The artificial ant agents are motivated by bionics. Most species of ants are blind yet they use a chemical substance, *pheromone*, to help them sense their neighbors' movements. The initial set of agents explore the network in a random manner. They leave trails by depositing pheromone, a method of communicating with other agents. At the same time, pheromone is also evaporating, but at a lower rate than deposition. The level of pheromone accumulation depends on the number of agents traveling through the same path with respect to the time taken, where pheromone evaporation plays an important role in route maintenance. A previous optimal route does not dominate, when network conditions change. By determining the amount of pheromone left by the agents, which shows the optimal route taken by recent agents, the current agent's probability of choosing the same route is higher. In this manner, the agents move towards an optimal solution by sharing their knowledge among neighbors, and the group behavior leads to an optimal solution in a network, where time is an important constraint.

There are three kinds of agents based on their primary functions: sensing, allocating and de-allocating. The sensing agent that traverses the network and communicates with its neighbors to reach the destination finding an optimal route. The allocator agents allocate the resources and monitor the transmission among active network links. The de-allocator agents release the trails laid by sensing agents and clear the sensed values. These agents ensure the optimal route to the destination using limited resources while learning the network environment. In the initial stages these tasks are computationally expensive, but once the agents adapt, the computational time, costs and tasks are minimized drastically. In the sensor network, the agents function in a way to minimize energy while tracking network requirements. Agents are not hardware entities separated from the network; instead, they are small data segments or commands collecting sensor information. The application of Ant System does not require special hardware.

In wireless sensor networks, sensor nodes are deployed randomly on a two-dimensional plane. The random placement of the nodes reflect the lack of a priori information that we are assuming for the network and its operational environment. Knowing the sensor nodes deployment a priori will improve performance, so we are considering a worst case scenario. The distance between the sensor nodes is evaluated by Euclidean metric.

The agents are distributed on the sensor nodes and move from node to node to form the routes among the nodes. The initial spread of the agents is in a random manner to speed up the search process. The ant agents accumulate pheromone as they traverse through the nodes, hence the distance traveled by the agents is one of the critical parameters that need to be considered while depositing the trails. The pheromone is updated by every agent upon completing a route by

$$\Psi_{ij}(t) = \rho\Psi_{ij}(t-1) + \frac{Q}{D_t \cdot E_t \cdot BER_t \cdot Link_t \cdot Hop_t}, \quad (1)$$

where $\Psi_{ij}(t)$ is the amount of pheromone at time t on the route from node i to node j. ρ is a constant between 0 and 1 to control trail memory. Q is an arbitrary constant to weight memory and current state. D_t is the total distance of the current route of the agent. E_t is the total energy that would dissipate along the route. Meanwhile, bit error rate (BER_t), link status ($Link_t$) and hops (Hop_t) in a possible route are also incorporated in the evaluation of pheromone as shown in Eq. (1), where the trails formed by the ant agents now depend on both the physical layer and MAC layer of a network.

The transition probability for the agents to take certain routes is calculated in Eq. (2) based on pheromone.

$$P_{ij} = \frac{(\Psi_{ij}\Gamma_{ij})^{\alpha} \cdot (\eta_{ij})^{\beta}}{\sum_k (\Psi_{ik}\Gamma_{ik})^{\alpha} \cdot (\eta_{ik})^{\beta}}, \quad (2)$$

where Γ_{ij} is the priority given to coefficients, which is uniquely defined in this paper, and will be discussed in more details later. α weights pheromone deposited by the ants. η is the performance factor defined in Eq. (3) as varying parameters of the ant agents, and β weights the performance.

$$\eta_{ij} = \sum_k W_k \cdot \frac{P_{actual,k} - P_{required,k}}{P_{actual,k}}, \quad (3)$$

where k is the index of the parameter set. The parameters, P, in consideration include D_t, E_t, BER_t, $Link_t$ and Hop_t. These parameters are normalized and weighted by W_k. The weights reflect the importance of parameters to the system, which greatly affect the decisions made by Ant System. The weights on performance parameters are provided by either partially ordered sets (POSets) [16] or an expert. In face recognition, the primary goal is to attain a low bit error rate with minimal energy. Thus these two factors are weighted more than the number of hops, link status or distance.

Once the network is set up, the ant agents are randomly placed on the network with their initial parameters configured to default settings. The simulation runs for a number of iterations or until a global optimal is reached. A legal route is "forced" by the use of a tabu list, where an agent can only visit a sensor node once. Each agent has its own "route memory" stored in the tabu list, on average energy, bit error rate, distance traveled and the response time, etc. When the route is complete, pheromone is laid down on the trail. The inefficient sensor nodes, which dissipate too much energy over a threshold, are avoided by taking an alternate route. Thus, the network is kept functional even if some individual sensors fail.

Based on the general layout of Ant System based routing, customized image processing is implemented to take advantage of the transmission. By wavelet or contourlet decomposition, the image is transformed to approximation coefficients and detailing coefficients at several levels, and some coefficients are more important in image reconstruction or transform domain recognition. The priority of the coefficients, Γ_{ij}, are set according to their importance. Three image processing schemes are evaluated based on their performance in a wireless face recognition system: in raw format, in compressed formats by wavelets, or by contourlets. Different priority levels can be specified for these transform coefficients along with different importance levels. Ant System is utilized to realize such customized and automatic priority adjustment.

IV. Simulation Results

The wireless channel is assumed to be Rayleigh flat and slow fading based on scenario analysis of wireless face recognition. The predicted BER (Bit Error Rate in bits/sec), energy and distance helps in making a decision whether the nodes in the current route are capable of communicating with its peers in the next iteration. The memory of the sensor nodes are very limited; hence, the messages are limited to 10 per stack.

After the images are transformed by wavelets of contourlets for compression, the detailing coefficients are assigned higher priority to ensure accurate transmission. The performance of prioritized transmission is evaluated by the mean square error of the reconstructed images and averaged over 1000 trials. The performance of coefficients v.s. original images is evaluated based on the face recognition rate for both distorted coefficients and raw images with equivalent amount of distortion, where, in both cases, low BER is ensured by the Ant System transmission. After the transmission, the data (either coefficients or original images) are thresholded by Stein's thresholding method [17] for denoising.

Fig. 1 shows the BER of DSSS-BPSK model for image coefficients with three different priority levels. The BER achieved for high priority coefficients is low, compared to low priority coefficients. It is due to the fact that Ant System weights more on the important data, and allocate limited resources more on the important data by self-tuning. Therefore, there is less overall distortion due to the wireless channels on original data.

Table. I lists the mean square error of the reconstructed images with or without the prioritization setup. It also compares the contourlet compression and the wavelet compression [14]. The result shows that the contourlet compression is quite competitive to the wavelet compression, and it's slightly better in cases with or without prioritization in data transmission [15]. Meanwhile, the prioritization of the coefficients realized by Ant System decreases the MSE in both cases.

TABLE I
MSE Comparison of the Coefficients Transmission with or without Prioritization

	Prioritization	
Coefficients	**With**	**Without**
Contourlets	4.1349	4.3653
Wavelets	4.7108	4.9863

Based on data transmission in the wireless sensor network, Table. II and Fig. 2 show the classification performance of face recognition system when coefficients are transmitted. Table. II lists the rank-1 face recognition rates based on different transmission schemes. Rank-k is defined as whether the true identity of the testing image is among the first k candidates provided by face recognition system. Rank-1 performance is the strictest requirement. Rank-k results are useful as well for further screening by other biometrics, other methods or manual screening. The transmission of coefficients, either contourlets or wavelets, is more robust than transmitting the original images, because the compression compacts the information in fewer coefficients, and the transmission is less prone to channel error. Meanwhile, prioritization preserves more important information more accurately, which improves the performance further.

TABLE II
Rank-1 Face recognition rates based on the transmitted coefficients and image

Contourlets		**Wavelets**		**Image**
With Priority	Without Priority	With Priority	Without Priority	
91.7949%	90.2564%	91.2821%	89.7436%	89.2308%

The face recognition algorithm implemented on a wireless system is Direct Fractional-step Linear Discriminant Analysis (DF-LDA) method [18], which is shown to work more robustly than the Eigenface method or Fisherface method [19]. A sensor network with 16 nodes is considered in simulation. Agents are randomly placed on the nodes. It is evident that using more ant agents leads to less computation time and higher performance. To ensure fairness, the network consists of equal number of agents and nodes. The total allowable hops for all simulations is assumed to be the same as the number of nodes in the network, or 16. The actual number of allowable hops is user defined, which varies depending on the problem assigned.

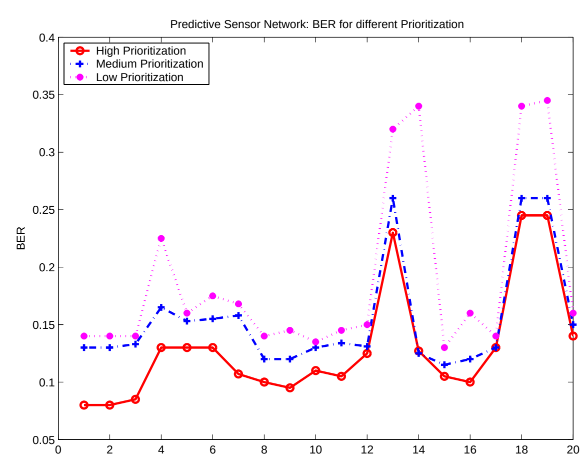

Fig. 1. BER on coefficients with different priorities. Coefficients are routed within wireless face recognition system.

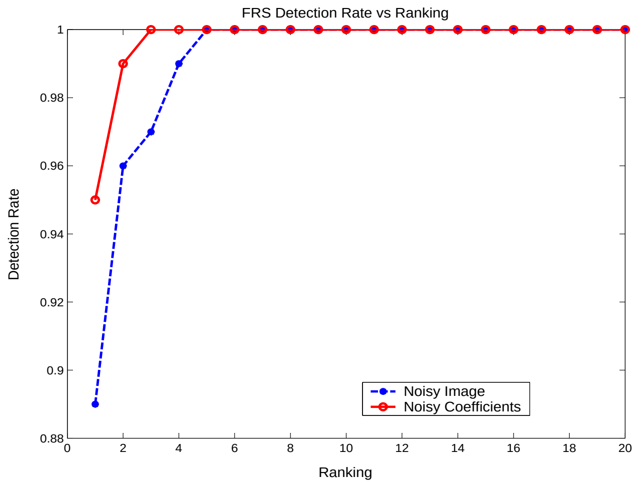

Fig. 2. Face detection rate versus ranking. The comparison is between transmitting original images and transmitting compressed coefficients.

In the traditional wired face recognition system, the data transmission is expected to be more reliable than the wireless transmission, and the rank-1 face detection rate based on eigenface method is 94%. This paper proposes to use a wireless sensor network for data transmission to make face recognition system more flexible in dynamic region of interest, in specific deployment of devices, and in sharing the face database. But with wireless fading channels, the imperfect data transmission is lowering the rank-1 detection rate down to 88% as shown by the blue dashed line in Fig. 2. However, if the contourlet or wavelet coding is first implemented to transform the image into coefficients to assign different priorities in transmission, more channel resource is allocated to the more important data, and final rank-1 detection rate is still maintained at 94% as shown by the red solid line in Fig. 2. Face recognition system provides not only the rank-1 candidate, but also other lower-rank possible identities. This property is useful for pre-screening and multiple combination with other modalities.

V. Conclusion and Future Work

This paper proposes to use Ant System in flexible and cost effective routing for wireless face recognition by integrating all performance parameters in a distributed and collaborative way, with appropriate weighting on the performance parameters. The performance parameters reflect the conditions in physical layer, MAC layer, and application layer. In order to further improve the transmission efficiency, we apply contourlet or wavelet transforms on face images, and transmit the coefficients with prioritization to allocate the limited resources efficiently achieving minimum energy consumption and reliable transmission. The wireless face recognition system achieves the same performance of a wired system, at 94% accuracy, with a short response time. Frequency Hopping Spread Spectrum (FHSS) and Direct-sequence spread spectrum (DSSS) are used to help alleviating denial of service attacks (DoS) caused by jamming, etc. This improves system quality of service (Qos), and prolongs network life span.

In the future, other artificial intelligence can be applied to enhance the learning ability of Ant System. Diversity or other forward error correction coding can be implemented for higher transmission accuracy. Knowing different jammers and predicting the attacks maintain the reliability of the network. More security features can be included into the wireless face recognition system to combat potential attacks.

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