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Interoperability Framework for Multimodal Biometry: Open Source in Action

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Abstract: In recent years identity management systems significantly increased the use of biometry. This process shifted this research area towards academia that in turn resulted with the rise of available biometric solutions, especially open source ones. Most of these solutions deal with only one biometric modality. The problem is that the price of the solution affects the precision and performances of the system. Open source solutions usually struggle with this issue since the funds for development are very limited. Possible solution can be found in using the multimodal approach that involves using several biometric modalities to improve preciseness and performances of the system. Unfortunately this opens another issue of interoperability among existing biometric solutions, acquisition devices and databases. This paper focuses on solving this issue, by proposing the interoperability framework for this purpose. Efficiency of the proposed framework was evaluated by using it as a development platform for developing a multimodal biometric application that combined three separate biometric modalities: fingerprint, face and voice. Proposed framework should further accelerate future development of biometric solutions.

Keywords: Interoperability, Multimodal biometry, Open Source, Framework, Security
Categories: D.2.12, D.2.11, D.2.13, K.6.5

1 Introduction

The development of the transportation and communication technology caused a significant increase in people movement in past years. In past decade alone air travel has grown 7% per year [Kroo, 11]. During last year airlines all around the globe transported 1.5 billion people on scheduled flights. In densely populated areas such as Europe people cross their state border up to several times a year. People are constantly changing their jobs, they move in search for better business opportunities, sometimes also in search for better education. The reasons are numerous.

In spite the fact that people should have full liberty to travel or change their living location, there are many difficulties and security risks brought by such open policy of people movement. When a person changes location, the process of accommodation to

the new space of living is sometimes a durable process. The person needs to establish a new relationship with its new government, municipal administration, education institution etc. The identity of that person comes to question. For example, in order for a person to continue its education in some other country, it is important for its future education institution to confirm that person's identity and to be aware of its previous level of education. This problem was defined as identity management [Williamson, 09]. Well established way of identifying a person usually involves comparing the visual appearance with a photo provided on the identification document. This process is not always reliable. Sometimes the photo differs from the actual state, and sometimes there is a need for an identification process to be done automatically, without human participation. In order to improve the process of identity management an approach that uses biometric features was introduced [Department of Defense USA, 07]. Biometric systems can be very useful in many aspects of everyday life. This is true especially due to the fact that a great quantity of communication now-days is done remotely. People perform shopping online, they use e-government services, perform business transactions, learn and educate themselves and maintain they personal relations. In all of these situations confirming the identity of the person on the other side is essential. It must be done to prevent cheating and access to sensitive data to unauthorized people. This is difficult if a person is remote, on the other side of the wire.

Initial application of biometry was in military environments [Department of Defense USA, 07]. This is analogue to the evolution of Internet technology. Initially it started as a military project and transferred to academic environment as ARPANET. This resulted with the expansion of Internet and enabled further development of many successful commercial applications. With the evident rise in needs for the biometric technology, academic institutions are increasing their involvement in to this area of research. Additionally, the advances in biometric technology are opening new spaces for a significantly larger use of biometry. Most of the biometric sensors are now quite affordable. Even smaller research budgets can now meet the expense of using them for development and testing. That in turn resulted in advances in open source community gathered around development of biometric solutions.

Since open source solutions are usually developed enthusiastically without proper funding, the result often implies lower precision in comparison to highly funded commercial and military projects. The possible solution to the problem of precision can be found in applying multimodal approach to biometry [Snelick, 05]. Term multimodal in this scenario signifies using different biometric modalities in identifying a person or to verify its identity. Some of those modalities can be fingerprint, face, hand-print, voice and others. The idea of using more than one biometric modality is based on the assumption that by combining biometric modalities the overall preciseness and performance of the system can be improved while also maintaining a low cost of technology. But in order to use several modalities a biometric system must be developed in such a way to be able to communicate with other solutions and products. Since open source community is constantly introducing us to new algorithms and solutions, the rising issue becomes how to integrate existing solutions in to one complete system. Open source community works without outside control and monitoring and resulting solutions usually lack the ability to easily work together. Even though some standards are set in

this area, they are not fully honoured in the open source community. Providing interoperability between different solutions, products, databases and other aspects of biometric systems is a difficult task. This uncovers the specific focus of our research, and that is to provide interoperability between existing open source solutions and products in order to be used together as a multimodal biometric system.

When all challenges are considered we can conclude that there is an evident need to narrow the gap between existing approaches to biometry and to speed up the process of distributing biometric technology to a wider audience. Our idea is to develop a framework with underlying protocols that will enable the generic connectivity between various solutions, sensors, algorithms and databases.

In next section we provide problem statement for given research. Third section presents existing research field. Next, we present our multimodal biometry framework, as a proposed solution to established problems. Section five gives design example and finally we conclude.

2 Problem Statement

Open source solutions represent a specific form of projects. Their development approach significantly differs from commercial way of conducting projects. They are driven by a completely different set of motivating factors. The financial funds are usually scarce and the main driving force is the enthusiasm of the developing team focused around a common goal. That goal is to use their knowledge to create software that solves a specific problem. The management structure of the project is informal. People that are in the development team are often experts on different technology that they prefer using. For this reason many of the open source solutions can be connected to a specific platform, usually operating system. Additionally, they use different development environments and programming languages.

The benefits of this approach are evident. They provide access to a specific knowledge to wide audience usually free of charge. They are useful to users as well as to developers.

But they also suffer from many disadvantages. Usability in open source system is usually disregarded, specifically in biometric systems where developers focus on the algorithms and performance. Also, deployment techniques vary from project to project. Some are deployed as out of the box solutions, while others can be deployed as libraries or supporting utility functions. The means of communication with the user also differ significantly. Sometimes user can operate these solutions through Graphical User Interface, while sometimes they are operated through batch commands. Rarely do they implement standard technology to support service oriented approach, such as web services.

Open source solutions usually use specific formats for storing of data, especially in biometry, where biometric data is diverse and sensitive.

Even though open source approach is convenient for development of unimodal solutions, it significantly complicates the process of providing interoperability between them for the purpose of multimodal use. This is not a trivial issue. There are several complex issues to be surpassed in order to achieve a functional multimodal biometric system.

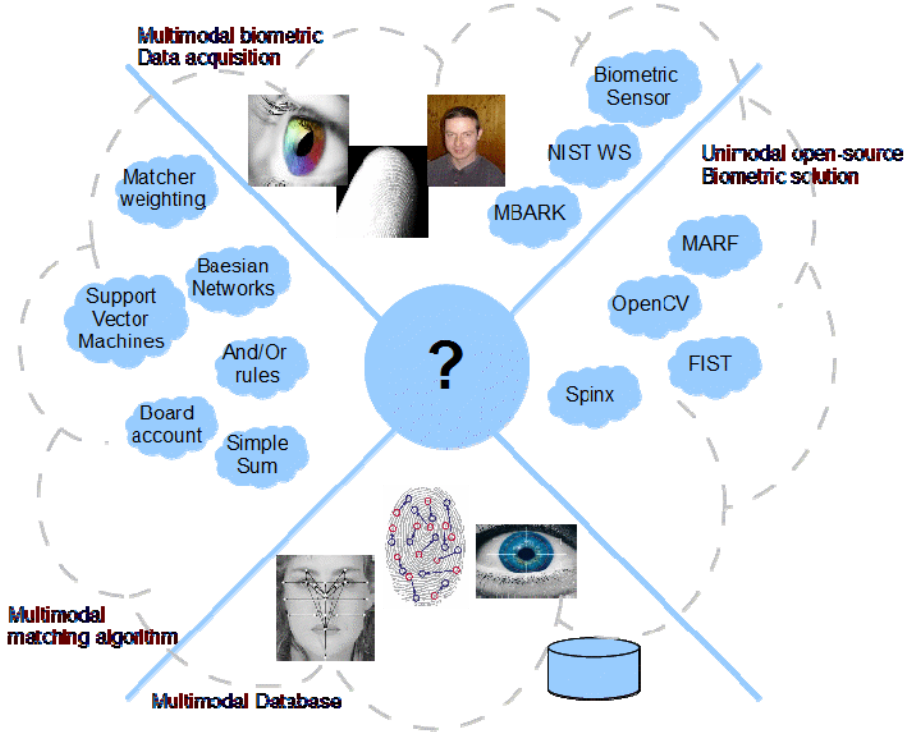

Figure 1: Interoperability problem for various biometric solutions, databases, acquisition and matching algorithms

The problem is how to provide interoperability between different open source biometric solutions and also how to enable integration of acquisition and data storage with matching algorithms in order to create a multimodal biometric system (See Figure 1). This problem can be decomposed in to ten specific issues.

First issue is how to enable a mean of communication between open source biometric solutions, sensors, data and future multimodal biometric system. Communication must support a distributed nature of variety of solutions that can be deployed on different platforms.

Second issue is how to manage biometric data. This process involves storing, feature extraction, search, edit and removing biometric data. It is necessary to provide access to data to every specific solution in a form it requires.

Third issue is directed at the mean of manipulating with different sensors and devices in the acquisition process. Many unimodal solutions implement this process as an integral part of their solutions and not honouring standards along the way.

Fourth issue concerns the decision making process in multimodal biometric systems. It is necessary to provide algorithms and processes to combine results and

scores for the decision making purposes. The optimal solution depends on the needs of each system.

Fifth issue targets usability of biometric systems. This process requires a unified mean of managing functionalities through simple and standardized user interface.

Sixth issue relates to problems of compiling, deployment and management of each specific solution.

Seventh issue targets reusability problem. Framework should support a possibility to reuse software components in different contexts.

Eighth issue is directed at security. There are several challenges in security. Since biometric data is sensitive all aspects of manipulating that data must be properly regarded. This includes biometric data acquisition, storage, transfer and processing.

Ninth issue is performance. This is opposite to previous issue, rising of security influences overall performance of the system. Using several solutions that came from different sources implies the fact they are not optimized to be used cooperatively. When biometric systems are in concern this is emphasized since in many cases the processing is done on a large set of data that is of the multimedia nature.

Final and tenth issue is standards. In order to provide a large application area of this system it is essential to standardize segments of this system, especially communication. It is also important to include existing standards and enable their operation within the framework.

Our approach to solving these issues is to propose an open source framework that will target these issues. Framework proposal will be presented in section four.

3 Existing Research

Multimodal approach in biometric systems is currently a growing research trend. Combining several different modalities of biometry can prove useful in solving many issues biometric systems face [Bowyer, 06]. Some of them are precision, cost or performance. Multimodal biometric solutions can use several levels of fusion of unimodal samples. The fusion can be performed on a feature level, score level and decision level [Ross, 01]. When feature level fusion is in question most researchers use combinations physical modalities such as fingerprint and face [Rattani, 07] or hand and face [Rossa, 05], but some researchers also combined physical modalities with behavioral such as face and voice [Ben-Yacoub, 99] or fingerprint and voice [Wang, 04]. When fusing on the score level, the solutions focus on using different forms of statistical and mathematical methods [Alsaade, 09; Jain, 05; Kumar, 08]. Finally, when fusion is done on decision making level, many different methods are used mostly from statistical and the area of business intelligence [Prabhakar, 02]. But the problem of multimodal biometry is not limited to handling and fusing biometric data in identification and verification process. The problem is linked to several other issues. One of the major early problems that biometrics faced was the lack of interoperability between different software applications and devices developed by different vendors [Gonzalez-Agulla, 09]. Research group situated at National Institute of Standards and Technology (NIST) worked intensively in some areas of providing interoperability in biometric systems. Their project MBARK (Multimodal Biometric Application Resource Kit) was directed at providing an application kit that focuses on providing interoperability in acquisition of different modalities of

biometric data [Biometric Clients Group, 08; Biometric Clients Group, 09]. Among other, they proposed a standardized language for client configuration [Arronoff, 08]. Based on that experience, their recent efforts are directed toward proposing interoperability in a broader sense, through web services [Arronoff, 11]. Currently this project is directed on providing interoperability between different devices and sensors. This is done by using web services-based biometric device interface.

Since the research community intensified efforts in development of different biometric solutions the problem of standardisation was brought in to attention. Different stakeholders formed BioAPI consortium in 1998, and combined their efforts with NIST during 1999 in order to produce BioAPI version 1.0 during year 2000 and improved version 1.1 in 2001 [BioAPI Consortium, 02]. This specification was accepted as an US national standard by American National Standards Institute (ANSI) with its register number INCITS 358-2002. The development continued, and version 2.0 published in 2005 was accepted as an international standard number: ISO/IEC 19784-1:2005 by International Organization for Standardization (ISO) [BioAPI Consortium, 07]. BioAPI provides abstraction layer over biometric devices and solutions, in order to enable easier manipulation by programmers. In order for BioAPI to be used, a biometric solution or a device must implement its interface. Unfortunately, many biometric solutions still do not implement this standard programming interface, even the commercial ones. When open-source biometric solutions are considered the situation is even worse.

One of the major drawbacks of this standard is that established data structures, as well as architecture, are defined in C programming language. In order to use BioAPI in some other platform, one needs to develop a wrapper around C data structures or code. There were some efforts in academia [Gonzalez-Agulla, 09] and in open source community to distribute BioAPI to a more contemporary development platform, such as Java [BioAPI java project, 09]. Still, this project has exactly the same data structures and interfaces as defined by original BioAPI standard, and there is no support for service oriented architecture.

There are two approaches to solving interoperability issue. They are generic and domain specific approach.

In the generic approach effort was made by [Obrenovic, 08] in order to enable easier integration of different open-source solutions. Proposed framework provides a transport layer, with many standard transport protocols as well as interchange of state between different software. Framework is established theoretically well and Java based implementation is provided. Additionally, adapters are developed for some of the well known open source software, such as OpenOffice, Google services, etc.

There are several downsides to using generic approach. It is less productive since it requires more effort to solve any specific issue. Additionally, performances of generic solutions are usually poorer than those of the specific.

We decided on using the specific approach that will target the area of biometric systems. Currently in that research area there are no ongoing efforts in order to enable integration of open-source biometric solutions. For this reason we developed a domain specific framework for interoperability of open source biometric systems in order to provide an open source platform for creating a multimodal biometry system. Next section provides a detail perspective in to proposed framework.

4 MultiModal Biometry Framework

Our approach to the defined problem is to develop a framework in order to surpass the stated issues in multimodal biometry. Framework should enable inter-communication between different kind of open-source biometric solutions, databases and sensors in order to enable implementation of multimodal biometry (see Figure 2.). Biometric solutions are usually not prepared for integrating purposes and they communicate with the user in a many different ways, such as: file system, standard console input/output, graphical user interface, library calls and web services. They are also developed using a wide variety of platforms. Some of them operate as a service while others require batch processing. In order to enable communication between them we suggest introduction of specific protocols. Major advantage of protocol communication instead of object serialization (as in BioAPI) is that protocol is platform independent. This way, protocol can be implemented for the variety of platforms and available solutions.

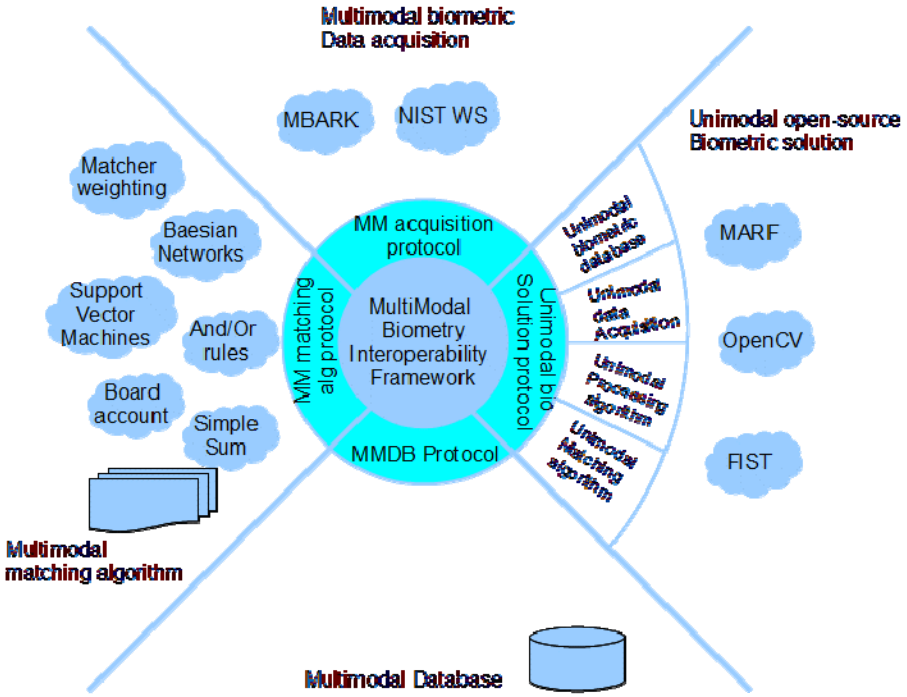

Figure 2: Logical view of multimodal biometry framework

Specific unimodal biometric solution can consist of following parts: biometric database, acquisition of biometric data, one or more processing and matching algorithms. Multimodal framework should provide the ability to use each specific part. One of the main functionalities in a unimodal biometric solution is performing identification or verification based on the sample retrieved from the device or

sometimes given in digital form. For a multimodal system to use that functionality it requires a way of communication with the unimodal solution. Required set of parameters for operating of unimodal solution may vary significantly. Also managing the input and output of each solution can be different. Method calls are often done using other means. Sometimes it's batch, sometimes web service and sometimes it's changing of configuration files. Ideal situation is that each unimodal solution communicates using the same protocol. Since that is not the case, protocol must be on a higher level. For unimodal solution to understand the protocol, a specific processor must be created to interpret the protocol messages and translate them in to actions unimodal system expects.

4.1 Framework configurations

The proposed framework represents a development platform for multimodal biometric solutions. For that purpose several framework configurations can be used.

4.1.1 Unimodal systems integration

Unimodal systems are not only used for identification and verification, but also for acquisition and communication with the database. Multimodal biometric systems can use complete set of functionalities of the unimodal solution starting from acquisition and ending with decision making. In that case all that multimodal system requires is voting. For example sometimes existing solutions should be connected in an Ad-hoc manner. In many other cases the resulting decision based on voting is not satisfactory, and more complex multimodal systems might require more.

4.1.2 System with multimodal acquisition

Using multimodal acquisition system in combination with other unimodal solutions, can sometimes provide a better final result. The acquisition process in multimodal systems usually implies using different devices and sensors to acquire different biometric data. Also sometimes different sensors are used in acquiring one modality of biometric data. For example fingerprint can be scanned using capacitive or optic scanner. Unimodal solutions support limited set of devices for acquisition. When a specific solution acquires data the main purpose is to provide its processing algorithm with the appropriate input. That often implies that output from that process is a specific template stored in a specific data structure and its reuse is not possible for some other solutions. Additionally, since acquisition process involves the subject, user interface during acquisition in multimodal systems should be consistent. If an operator is forced to use different interfaces in acquisition process for different modalities, the user experience will suffer. Typical representative of such system is the one where acquisition process is distributed and after that all other stages of the system are centralized.

The problem of acquisition in multimodal biometry is essential and that was identified by NIST researchers. They worked on an open source project called MBARK. They attempted to provide a unique tool for the acquisition process in multimodal biometry. Their work also involved specification of web services to be used in for accessing sensors in a universal way WS Biometric Devices (WS-BD). It is important for the framework to enable integration of such solutions in to a complete

multimodal biometric system. This is why framework includes multimodal acquisition protocol that deals with such solutions.

4.1.3 System with multimodal database and acquisition

Unimodal biometric systems usually operate with the database developed specifically for its purpose. The specific nature of the unimodal solution usually implies that one identity is represented with one biometric data record in the database. That biometric data is usually in a form suitable to the algorithm. In multimodal biometric systems requirements for a biometric data can vary. One identity in such a database is represented with several biometric modalities, and each modality can have multiple representations (see Figure 3.). Data can be raw data as recorded from the device, and also derived as templates that were a subject of some processing. Additionally, different modalities can be fused in to a single biometric data. Database model for a multimodal biometric system must support all this requirements and provide specific solution biometric format. This is necessary in order to provide integration of existing unimodal solutions. Centralizing database will improve security of biometric data but will raise the question of performance, especially for identification purposes. Example of such system is police. In that case acquisition process is done once, but data is accessed and used in many occasions. Since in this type of systems performances are a major concern, typically specialized hardware is used for implementation of centralized database. In our solution, the unimodal system is provided with the direct access to biometric data through database interfaces.

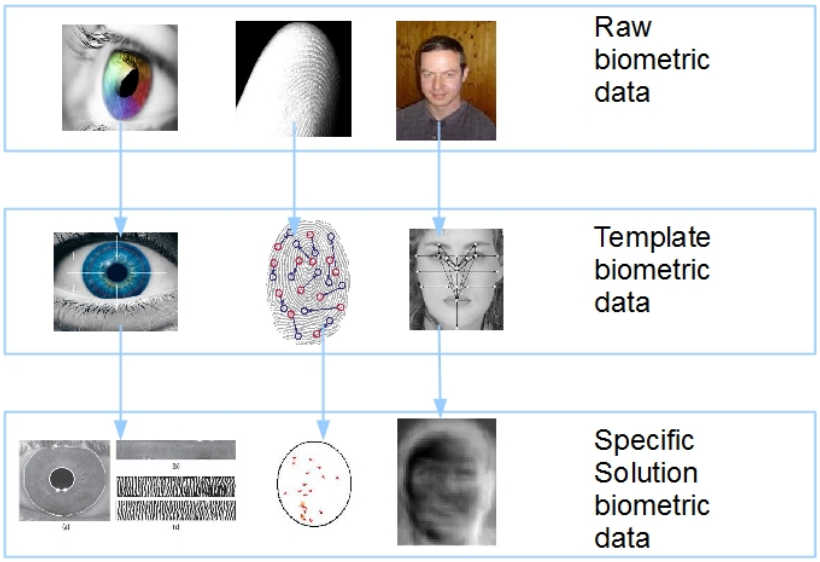

Figure 3: Multimodal biometric database model

4.1.4 System with multimodal database, acquisition and matching algorithm

Described segments of our framework enable integration of open source biometric solutions with the process of multimodal acquisition and with the multimodal database. But in order to complete the decision process on a multimodal level it is necessary to include the decision making activities. Based on the scores retrieved from unimodal systems the decision is made using some statistical and other method forms. Some of those methods are implemented as algorithms in an open-source solution. They also have different ways of management and control and expect different set of parameters. This is why a protocol is made that provides a link between the results retrieved from unimodal systems and matching and processing solutions. For those matching and processing solutions that do not implement that protocol, a specific processor must be developed to convert protocol commands in to actions that specific system expects. Complete multimodal solution that includes all possible functionalities can be useful in many occasions. It can be used in tracking and surveillance in airports, cities and many other situations where only non invasive methods for acquiring biometric data can be used. Data acquired through non invasive methods is usually of lower quality (for example photo from surveillance camera), which lowers the precision of unimodal solutions. This is where multimodal matching algorithm can provide improvement of precision.

4.2 Development issues

As mentioned, proposed framework can be used as a development platform for specific biometric solutions based on open source. Unfortunately, open source software often has a complicated installation process. Usually it starts with download from repository, then compilation followed by deployment and putting in to service. In order to combine several solutions, often it is necessary to deal with many different deployment platforms. One of the goals of our framework is to automate a process of installing and deploying unimodal solutions. Since each unimodal solution has a different set of functionalities and parameters it requires, our framework supports the process of initial handshake between multimodal and unimodal system. During this handshake process unimodal solution informs multimodal system of its functionalities and the parameters it requires. Also multimodal system can track the state of unimodal system and distinguish if the system is active, processing, available or unavailable.

4.3 Continuous-time biometric systems

Currently, multimodal biometric solutions provide the identification or verification based on a single transaction system, where a set of functionalities is performed and a decision returned. But with the development of behaviourist biometric systems, and also with advances in surveillance systems the need for continuous operation of multimodal system is emphasized. For example, tracking and identifying a person from a video feed, voice stream etc. With this in mind, our framework supports this mode of operation by introducing a concept of session. Communication inside this framework can be based on a single request/reply method, but also it can be session based (several request/replies per session).

5 Design Example

Our design example represents a specific implementation of multimodal biometric solution, based on the proposed framework. For the development of our multimodal application we used Java environment. Initially, we worked on the selection of the available open source unimodal biometric solutions to integrate in to our system. We decided on limiting ourselves to three modalities that are often used in research, face, fingerprint and one behaviorist modality such as voice. After extensive research on this subject and testing a group of available solutions we narrowed our choice to three solutions.

Biometric modality of face was included through the software package called OpenCV. OpenCV (Open Source Computer Vision) is a library of programming functions for real time computer vision [Bradski, 08]. OpenCV project was initially an Intel Research initiative to advance CPU-intensive applications, part of a series of projects including real-time ray tracing and 3D display walls. Over time it grew in to an extensive software solution that supports many aspects of computer vision. Functionalities we used were face detection and recognition. This system uses the Eigenface method for its face recognition module. Important aspect of this solution is that it supports work on several platforms, including some mobile. In our case we deployed it on the Microsoft Windows 7 environment.

For the fingerprint modality we decided on using the solution called NBIS (NIST Biometric Image Software) [Watson, 10] developed by National Institute of Standards and Technology. It is a set of utilities that provide much functionality for dealing with fingerprint modality. In our case we used MINDTCT unit to extract fingerprint characteristics and BOZORTH3 as an algorithm for matching based on minutiae.

Finally for the behaviourist modality of voice we utilized functionalities of MARF (The Modular Audio Recognition Framework). MARF is an open-source research platform and a collection of voice/sound/speech/text and natural language processing (NLP) algorithms arranged into a modular and extensible framework facilitating addition of new algorithms [Mokhov, 10]. This solution is written in Java programming language. It was developed using modular approach and it provides solid abilities for extension. This solution provides several algorithms for signal normalisation, feature extraction and for matching.

Since none of this solution provides a standard interface for communication we needed to implement a specific adapter that will convert protocol commands defined by our framework in to concrete actions (see Figure 4.). These commands are represented on diagram as IUMCommand interface, exposed by adapters.

OpenCV solution, as mentioned, was deployed on Microsoft Windows 7 platform. In order to provide interoperability with our multimodal solution we needed to find the best possible way to bridge the gap between our communication protocol and functionalities of the solution. OpenCV is essentially a software library that can be used as a building block of future applications. Due to that fact, and the fact that communication protocol is platform independent, the best approach is to develop the adapter using the technology that is native to that library. We implemented our adapter using C++ language, that uses OpenCV library as a part of our framework. Since interfaces that are used as communication protocol are defined, when a specific adapter implements that interface a reusable solution is provided. Future solutions that

are developed using the same platform can use the same adapter for a communication towards multimodal system. The only segment developer must implement is the segment that translates protocol commands in to specific actions for that solution.

Next solution we used is NBIS for dealing with fingerprint modality. In this case, solution is developed in C language as a set of standalone utilities, managed by console interface. For this solution we developed adapter in Java language that is capable of translating protocol commands in to console actions NBIS expects. This way adapter invokes processes of needed utilities and accepts the output that these utilities generate and send back to the console. Further the adapter analyses the response and converts it to a response message according to defined protocol. Since this solution has a specific console interface for management this specific adapter can be reused for any other solution that uses the same method.

Solution we used for voice recognition is also implemented as a program library written in Java language. In this case the easiest approach was to write the adapter utilizing Java platform that uses MARF library as its integrating part. Communication layer that works with protocol is identical as in previous case. This is a good example how framework provides reusability of components.

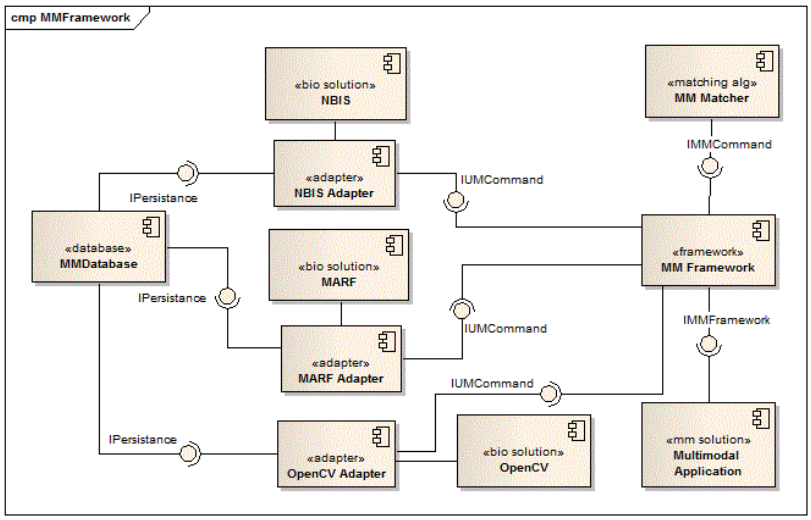

Figure 4: Logical Component Architecture of the Developed Multimodal System

According to our framework, recommendation is to use centralized multimodal database. In this multimodal system, we honored this principle and designed and populated our database. We acquired biometric samples from 39 subjects. Modalities included were fingerprint (index and middle-finger on both hands) using optical and capacitive scanner, photographs of face from multiple angles, video of the face in lateral movement, palm-print using optical scanner and voice sample. In this case we used only samples for fingerprint, face and voice. Since each of the solutions uses its custom database, we needed an interface that will adapt the needs of each specific system to our multimodal database. In this case commands are interpreted through

interface IPersistance (see Figure 4.) exposed by our multimodal database system. The adapters we developed use these interfaces in order to manage the needed data. Interface provides the ability of adding raw data, recording templates and features. Specific adapter can implement those aspects of the interface the specific solution requires. Most of the existing solutions work with file system and expect biometric data prepared in a designated folder. In order to redirect those calls toward our database, adapter detects the access to file and then represents the file stream that then on the other side communicates with the database and provides the required biometric data. In this manner we can insist on authentication for accessing the data and can also secure the communication channel.

Using our framework we developed a multimodal biometric application that is logically divided in to three layers. First one is a layer in charge of communication. That layer realizes communication protocol, provided as an interface IMM Framework (see Figure 4.). This interface provides a link to other segments of the framework, and should be reused for development of other applications. Second layer is application generic layer that is used for development of multimodal biometric systems. Basic functions provided in this layer include the component container for user interface of each unimodal solution, component for visualization of statistical analysis of system performance including a graph form and user interface for multimodal decision making purposes. Third layer is application specific and depends on the application needs.

Our multimodal biometric application supports several working modes (see Figure 5.), enrolment, identification, verification and evaluation. Enrolment is a process of introducing new biometric data for a person. Identification is a mode of comparing sample data to a set of data already enrolled in a database in order to identify a person. Verification mode is a form of confirmation of a person's identity by comparing data samples to that persons data already enlisted in the database. Evaluation mode provides the ability to compare the preciseness of each unimodal solution, as well as compare results retrieved using applied multimodal normalization and matching algorithms.

Each unimodal system provides different set of functionalities. In order to provide all the required functionalities to multimodal system for management and decision making purposes, multimodal system must be informed with the abilities of each unimodal system. In our framework this process is achieved during setup stages of each unimodal system. Each unimodal system reports its functionalities to multimodal system during the handshake process and multimodal application then installs a plug-in interface for management of that unimodal solution. In our case this is done by using plug-in pattern, where for each solution a user interface is added to a prepared container. Each unimodal interface implements methods that are pre-written for easier integration in to combined multimodal interface. Resulting user interface is integrated in to container, in this case tabular panel (see Figure 5), and presented to the user.

Next step is to include score normalization methods and fusion algorithms. We developed a component MM Matcher (see Figure 5.) to provide these functionalities. It implements interface for communication with the rest of the framework called IMMCommand. Score normalization techniques are targeted by some research but unfortunately the implementation of the achieved results still lacks in open source community [Alsaade, 09]. For this reason we set out to implement several score

normalization methods in Java. Methods we implemented were MinMax, AdaptiveQLQ, Tanh i Z-score [Alsaade, 09]. User can choose one of these methods. Before that, user chooses which modalities to include in the process of decision making. After choosing the score normalization technique next in line is choosing one or more fusion techniques. Since this is also disregarded subject in open source community, we also implemented, using Java, several fusion techniques, such as SimpleSum, MaxFusion, MinFusion, MatcherCoefficient, UserCoefficient [Alsaade, 09].

User can choose a set of fusion techniques that will be performed on the same set of data. In our system, a testing mode of operating is achieved that uses a set of biometric samples to cross examine system efficiency. It performs individual matching algorithms on a test set of data, alternatively using one as impostor (subject representing as someone else) against the remaining set. Then it performs score normalization and fusion in order to get the multimodal decision. In our example fusion is done on a decision level.

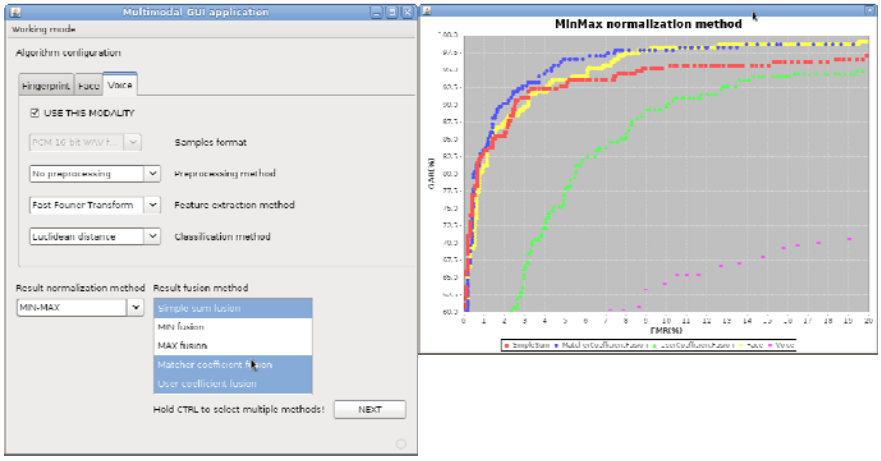

Figure 5: Screenshot of Multimodal Biometry Application

The final result is displayed in a form of a graph (see Figure 5.) that compares the ratio between Genuine Acceptance Rate and False Match Rate (GAR/FMR). Yellow and pink collection of points provides the relation retrieved from unimodal solutions for two selected modalities, face and voice respectively. Other three colors represent results after using different fusion techniques (Red - SimpleSum, Blue - MatcherCoefficientFusion, Green - UserCoefficientFusion). User can now analyze the achieved result and use it in configuration of the multimodal system. In this example it is clear that combination of face and voice improves overall poor preciseness of voice recognition if appropriate matcher algorithm is chosen.

Depending on the needs of each system user can adjust acceptance rate of the system. For instance in military systems it is very important to minimize False Acceptance Rate to improve security and limit unauthorized access. On the other hand

systems for attendance control such as those in some company or classroom require higher performance and can for that purpose sacrifice low False Acceptance Rate.

This way framework provides configuration and adaptation of multimodal system to a specific purpose that often lacks in off-the-shelf solutions.

6 Conclusion

Multimodal biometry is a growing research field. Open source community started to develop various solutions applicable in that domain. Currently one of the major issues in this area is how to provide interoperability among different biometric solutions, technology and products. Our work concentrated on solving the interoperability issue by developing a framework that enables flexible development of multimodal biometric systems.

During our research we identified ten issues that target the area of multimodal biometry. The proposed framework should provide a solution to these issues in a successful way. In order to solve the issue of communication we developed specific protocols. Main advantage of protocol based approach is platform independence and protocols can be implemented in a variety of platforms and solutions. Framework also targets the issue of managing biometric data as well as issue of acquiring them by different types of sensors. This is done by creating a centralized multimodal biometric database and the specific protocol for its management. Another segment of the framework defines a protocol that enables integration of multimodal acquisition systems (such as MBARK).

Important segment of the multimodal biometric systems is the decision making process. Our framework relates to this issue by enabling easy integration of different kinds of matching and normalization algorithms. Additionally, we developed several algorithms using our framework as development platform. Another issue we set out to solve is the unification of communication between user and multimodal biometric system. Our framework supports unified user interface as well as means of easy deployment and administration of each component.

One of the main goals of this framework is to speed up the future development of multimodal biometric systems. This is why framework is developed in such a manner that reusability is provided for each constructing component.

Security and performance are major issue in biometric systems, especially multimodal systems. They are opposed to each other and their goals collide. For example centralization of database improves security but negatively influences performances. Our framework provides a good basis for establishing balance between these two goals depending on the specific needs and the context.

Final and tenth issue is standards. Our framework is open for implementation for variety of standards.

We developed a multimodal biometric application based on our framework. We integrated three open source biometric solutions that deal with three separate modalities: face, fingerprint and voice. Evaluation of our system provided insight in to benefits of using this multimodal approach. Even though we used open source solutions that are not singularly most precise in their domain, when used in multimodal context in combination with other modalities the overall preciseness of the system improved.

Our initial idea is to start an open source project that will involve the community in further development of this framework. One of the first efforts of our research groups will be to finalize this process and make this available to a wider audience. Upon that, community will be able to contribute by including open source biometric solutions in to the framework. By increasing the number of supported solutions the focus will shift towards development of new normalization and matching algorithms as well as improvement of existing ones. Another activity planned is to provide support for BioAPI standard so that solutions that implement that standard can easily integrate in to the framework.

Interesting approach that would be good to incorporate in to the framework is to consider including classification and clustering algorithms in order to identify users on the basis of their biometric data. One approach that can be considered useful is using reusable component based algorithms [Delibašić, 2011; Suknovic, 2011; Delibasic, 2009].

Finally, non functional requirements of the framework such as usability, reusability, security and performance always leave room for improvement.

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References

[Alsaade, 09] Alsaade, F., Ariyaeeinia, A., Malegaonkar, A. , Pillay, S.: Qualitative fusion of normalised scores in multimodal biometrics, Pattern Recognition Letter, 30, 5 (2009), 564-569.

[Arronoff, 08] Aronoff, M., Michaels, R. J.: The Biometric Client Configuration Language, National Institute of Standards and Technology, U.S. Department of Commerce (2008)

[Arronoff, 11] Aronoff, M., Biometric Web Services (2011), http://www.nist.gov/itl/iad/ig/bws.cfm

[Ben-Yacoub, 99] Ben-Yacoub, S., Abdeljaoued, Y., Mayoraz, E.: Fusion of Face and Speech Data for Person Identity Verification, IEEE Transactions on Neural Networks, 10, 5, (1999), 1065-1074.

[BioAPI Consortium, 02] BioAPI Consortium, ANSI INCITS 358(BioAPI Ver 1.1) (2002), http://www.bioapi.org/m1projects.asp

[BioAPI Consortium, 07] BioAPI Consortium, ISO/IEC 19784-1 (BioAPI Ver 2.0) (2007), http://www.bioapi.org/isoprojects.asp

[BioAPI java project, 09] BioAPI Java open source project, (2009), http://sourceforge.net/projects/bioapijava/

[Biometric Clients Group, 09] Biometric Clients Group, Image Group, Information Access Division, Information Technology Lab – "MBARK brochure", National Institute of Standards and Technology, U.S. Department of Commerce (2009)

[Biometric Clients Group, 08] Biometric Clients Group, Image Group, Information Access Division, Information Technology Lab – "Public Build Instructions for MBARK", National Institute of Standards and Technology, U.S. Department of Commerce (2008)

[Bowyer, 06] Bowyer K., Chang, K. I., Yan, P., Flynn, P. J., Hansley, E., Sarkar, S.: Multi-modal Biometrics: An Overview, In. Proc. Second Workshop on Multi-Modal User Authentication, Toulouse, France (2006)

[Bradski, 08] Bradski, G. R., Kaehler, A.: Learning Opencv, 1st Edition (First ed.)., O'Reilly Media, Inc. (2008)

[Delibasic, 2009] Delibasic, B., Kirchner, K., Ruhland, J., Jovanovic, M., Vukicevic, M.: Reusable components for partitioning clustering algorithms. Artificial Intelligence Review, 32, 1-4 (2009), 59-75.

[Delibašić, 2011] Delibašić, B., Jovanović, M., Vukićević, M., Suknović, M., Obradović, Z., Component-based decision trees for classification, Intelligent Data Analysis, 15, 5 (2011), 671-693.

[Department of Defense USA, 07] Department of Defense USA, Report of the Defense Science Board Task Force on Defense Biometrics, Office of the Under Secretary of Defense For Acquisition, Technology, and Logistics Washington, D.C. 20301-3140 (2007)

[Gonzalez-Agulla, 09] Gonzalez-Agulla, E., Otero-Muras, E., Garcia-Mateo, C., Alba-Castro J. L.: A multiplatform Java wrapper for the BioAPI framework.Comput. Stand. Interfaces 31, 1 (2009), 186-191.

[Jain, 05] Jain A., Nandakumar, K., Ross, A.: Score normalization in multimodal biometric systems, Pattern Recognition, 38, 12 (2005), 2270-2285.

[Kroo, 11] Kroo, I.: The Airline Industry (2011), http://adg.stanford.edu/aa241/intro/airlineindustry.html

[Kumar, 08] Kumar, A., Kanhangad, V. Zhang, D.: Multimodal biometrics management using adaptive score-level combination, In Proc. 19th International Conference on Pattern Recognition ICPR (2008), 1-4.

[Mokhov, 10] Mokhov, S. A.: Evolution of MARF and its NLP framework, In Proc. Third C* Conference on Computer Science and Software Engineering (C3S2E '10), ACM, New York, NY, USA (2010)

[Obrenovic, 08] Obrenovic, Z., Gasevic., D.: Open Source Software: All You Do Is Put It Together. IEEE Software, 24, 5 (2007), 86-95.

[Prabhakar, 02] Prabhakar, S., Jain, A. K.: Decision-level fusion in fingerprint verification, Pattern Recognition, 35, 4 (2002), 861-874.

[Rattani, 07] Rattani, A., Kisku, D. R., Bicego, M., Tistarelli, M.: Feature Level Fusion of Face and Fingerprint Biometrics, Biometrics: Theory, Applications, and Systems, In proc. First IEEE International Conference, Crystal City, VA (2007), 1-6.

[Ross, 01] Ross, A., Jain, A. K., Qian, J. Z.: Information Fusion in Biometrics, In Proc. 3rd International Conference on Audio- and Video-Based Person Authentication (AVBPA) (2001), 354-359.

[Rossa, 05] Rossa, A., Govindarajanb, R.: Feature Level Fusion Using Hand and Face Biometrics, In Proc. of SPIE Conference on Biometric Technology for Human Identification II, Vol. 5779, Orlando, USA (2005), 196-204.

[Snelick, 05] Snelick, R., Uludag, U., Mink, A., Indovina, M., Jain, A.: Large-Scale Evaluation of Multimodal Biometric Authentication Using State-of-the-Art Systems., IEEE Trans. Pattern Anal. Mach. Intell., 27, 3 (2005), 450-455.

[Suknovic , 2011] Suknovic, M., Delibasic, B., Jovanovic, M., Vukicevic, M., Becajski-Vujaklija, D., Obradovic, Z.: Reusable components in decision trees induction algorithms, Computational Statistics, 27, 1 (2011), 127-148.

[Wang, 04] Wang, Y., Wang, Y., Tan, T., Zhang, D., Jain, A.: Combining Fingerprint and Voiceprint Biometrics for Identity Verification: an Experimental Comparison, Lecture Notes in Computer Science, Springer Berlin / Heidelberg (2004), 289 – 294.

[Watson, 10] Watson., C., Garris, M., Tabassi, E., Willson, C., McCabe, R., Jannet, S., Ko, K.: User's Guide to NIST Biometric Image Software, National Institute of Standards and Technology (2010), http://fingerprint.nist.gov/NBIS.

[Williamson, 09] Williamson, G., Yip, D., Sharoni, I., Spaulding, K.: Identity Management: A Primer. MC Press, LLC. (2009)