In the paper we present our project concerning a modular image processing environment to be used as a forensic tool by law enforcement laboratories in the analysis of crime scene videos and images. It is designed to overcome one of the main drawbacks of standard image processing tools, mainly the lack of full control and documentation on the operations which have been performed on the images; moreover, some advanced nonlinear operators have been introduced, which can provide improved performances for some selected tasks.

INTRODUCTION

Video-surveillance systems are widely used for both crime detection and prevention, and their presence in everyday life is constantly growing, implying a reasonable debate between people who claim the right for their privacy and on the other side those who rather prefer personal security. Besides these ethical and subjective matters, we are interested in technical problems caused by use of surveillance cameras and their effectiveness. Economical and practical problems are the main factors causing the poor quality often provided by the adopted systems; this make us wonder if they can be considered more a deterrent for criminal actions rather than a valid identification system. However, in many cases, even a very deteriorated image could be of some value both during the first steps of the investigation and in courtrooms.

Consequently, images and sequences coming from video-surveillance systems often need to be digitalized and processed by some software to enhance features useful for crime analysis. Generally, this is done either to overcome the limits of the overall systems or to reduce the different kinds of corruptions that have been introduced in the acquisition, conversion or storage processes of the data. Typical problems to deal with are:

- poor resolution of the images or the need to increase the size of some details of the image;
- lack of contrast;
- presence of different types of noise or disturbances;
- blurring caused by motion or lack of focus;
- jitter or misalignment of lines due to the wear of video cassette recorder (VCR) heads;
- geometric distortions (caused for example by wide-angle lens cameras); in some cases it is important to reconstruct the correct sizes of the objects for feature detection and extraction, such as the numerical estimation of biometric features of subjects inside the image.

Each operation done on the image must be proved and certified, while the use of commercial software could be, in theory, not objective and reliable from a legal point of view, due to the fact that its source code is usually not public; a complete knowledge of each step of the applied algorithms is needed to obtain full objectivity and to guarantee that the same result can be obtained by anyone anywhere. Open-source software, such as GIMP [1], meets this need, since each single part of the process is totally visible and open to scrutiny. However, open-source programs may not be equipped with some advanced operators which have been appeared in the literature for common tasks such as zooming or image noise reduction, or may lack tools to treat specific problems such as recovery of a video recorded by a defective VCR.

In this paper, we present MIPE, the Modular Image Processing Environment we are presently developing in cooperation with the Forensic Science Laboratories (RIS) of Italian Carabinieri in Parma, Italy, to tackle with the above mentioned problems. After a brief review on the state-of-the-art systems (Sec. 1), we describe the adopted software architecture and some of the advanced operators we have introduced in our system (Sec. 2). Finally, we present some experimental results (Sec. 3) and we draw some conclusions, together with some directions for further research and development.

1 STATE OF THE ART

Presently, several products exist on the market which are dedicated to scientific analysis of image-based information for forensic science applications; we can recall, in no particular order and with no intention to be complete, dT ective by Avid and Ocean Systems [2], Impress by Imix [3], StarWitness Video by Signalscape [4], Video Analyst by Intergraph [5], and Video Investigator by Cognitech [6].

There is a strong connection between the evidence source and the processing software, so forensic image analysis products are a combined software and hardware solution, aimed first at acquiring a secure digital copy of the evidence video or images, thus preventing possible damage of the original, and then at processing them as needed. The vendors offer different system solutions to satisfy the forensic image professional needs to capture, analyze, enhance, and edit all major video formats. The systems are then varied in term of software capabilities (i.e. available filters, algorithms and proprietary operations, courtroom oriented functions) and hardware characteristics (e.g. PC RAM amount, in-
stalled graphic and acquisition cards, available media readers, additional equipments such as VCRs and printers). Here we are mainly interested in the software component, and the aim of MIPE is to become an affordable system for image restoration and enhancement in the forensic field, using validated, bledding edge, widely accepted and open to scrutiny image processing algorithms to extract the required information from the filmed sequence.

All the aforementioned programs can perform contrast and brightness adjustment, histogram equalization and editing, zooming, mirroring and rotation of the images under analysis. Some of them give the ability to customize deblur filters kernel and offer noise filters (both classical and proprietary ones, such as JPEG dedicated deblockers). Actions can also be performed as inter-frame operations; for example, motion deblur filters allow, in a more or less user-friendly way, the restoration of the details of a moving object, exploiting the information related to the object which is present in several frames of the recorded sequence. Also demultiplexing algorithms are available, so that different camera views can be converted into video clips (see [7] for a review about video contents indexing), thus allowing the isolation of the crime scene, and deinterlacing. Finally, each case can be fully organized thanks to archive and back-up facilities, and each program creates an audit log for each case, in order to make it suitable for presentations in courtrooms. However, even if these analysis systems offer the ability to follow and write down each step of the image processing operations on a log file, they do not provide full access to the applied algorithms. In fact, although the performed operations are recorded together with their parameters, the employed algorithms may be not public.

2 THE PROPOSED SIGNAL PROCESSING SYSTEM

In this section, we first describe the software architecture and which kind of functions are currently available, then we give some details on some of the advanced operators which have been included in our system.

2.1 Software architecture

As already mentioned, MIPE is an open-source software developed in the University of Trieste, Italy, to meet the requests of, and specifically developed in cooperation with, the RIS of Parma. The main ideas upon which MIPE is based are the following:

- modular software, easy to update or integrate with new features whenever it is needed;
- open-source software, in the way that anyone can verify and test the reliability of the algorithms and their implementation;
- implementation of state-of-the-art algorithms, thus granting not only transparency but also an improvement in the quality of results with respect to general purpose commercial software;
- complete knowledge of the work done on an image: a trace of each operation applied to each image is kept, in order to both provide full documentation and to be able to duplicate, if necessary, the processing.

- development in close cooperation with the final user, in order to understand his or her real needs and to verify the proposed architecture and algorithm on the field.

In order to meet these requirements the software has been designed following some guidelines which allow us to come as much closer as possible to the real needs of the final user. The chosen development environment is Matlab 7 by The MathWorks [8]: this choice is due to the high level style of programming adopted in Matlab, which both ensures easy understanding of the code and allows to improve the productivity, using a great number of either generic or very specialized built-in functions available in its toolboxes. Even if we are using a proprietary environment we can still say the source to be open: we provide in fact both the executables and the code of the software; most of the included advanced filters are developed by us and the ones currently implemented through Matlab functions are present mainly for reference and mostly going to be rewritten by us in future. However it must be stated that also using high level Matlab functions doesn’t affect our purpose, since the code of most of them is publicly visible. Generally only very low level and highly optimized functions are not readable and they must be used anyway, since they perform very basic mathematical operations implemented through compiled libraries [9].

As stated above, the high level style of programming adopted in Matlab can improve a lot the readability of the code with respect to a traditional programming language: this is in strong connection with the case of a possible scrutiny of the code and its ease of understanding during a trial. It has to be said that Matlab is noticeably slower if compared to traditional programming languages such as C or C++; however, when considering the computational power nowadays reached by PCs, this fact can be considered of secondary importance.

In order to grant the traceability of the work done on every image, MIPE writes on a log file the list of all the performed operations, complete of the related parameters, and, most importantly, any single image processing operation is fully documented by mean of the source code included with the environment and providing the reference linking to the scientific article from which the algorithm has been implemented. In this way trained personnel can repeat the image processing steps and produce an output image matching the one produced by the forensic image professional [10].

Another issue to be taken into account is to allow the end-user to easily update or customize the software, especially if using the tool in the classic Matlab interpreted way, rather than using its compiled version. For this reason, MIPE has been built in a modular way: the addition or modification of an arbitrary function to the core of the program is straightforward, so that the integration with the rest of the system (including the log generator) and to the graphic user interface (GUI) is almost automatic. In this way we hope that, in the spirit of open-source software, we will give the people a tool to easily implement their image processing functions and at the same time obtain some feedback and improve our work through them.
Finally, some specific operators have also been implemented to correct problems on images coming from VCRs with corrupted synchronization signal, together with an early-stage tool dedicated to the import of frames from a video sequence, which allow the user to demultiplex and deinterlace a sequence coming from different cameras.

2.3 Some advanced operators

As already mentioned, both standard algorithms and some advanced ones have been implemented in MIPE. In this section, the most relevant details related to some of the latter are reported.

For what concerns image enhancement, image interpolation and noise smoothing, rational filters [11] have been chosen. Generally speaking, rational filters are nonlinear operators expressed as a ratio between two polynomial functions of the input data. They have been proved to outperform traditional filtering techniques, still maintaining a rather low computation complexity, mainly thanks to their capability of gradually adapting to the image local characteristics. As an example, in the context of edge preserving noise smoothing it is possible to operate differently on the high frequency components of real edges (to be preserved) and unwanted noise (to be suppressed).

Currently, four implementations of rational operators are adopted in the software, namely for noise smoothing [11], unsharp masking [12], pixel interpolation [13], and reduction of blocking artifacts in JPEG compressed images [14]; these algorithms, originally designed for gray level images, have been suitable extended to color ones.

As an example, for what concerns image interpolation, different approaches for the color processing have been considered, giving somehow similar results; the chosen one is based on the conversion of the original RGB image into the YIQ color space. The original algorithm computes each output pixel as a weighted sum of its neighboring pixels; in our case we compute the weights on the Y component, then these weights are applied to all the three YIQ components, and finally the image is converted back to RGB. It must be said that some other modifications have been applied to the original algorithm, such as the introduction of a new parameter which improves the visual quality of the resized image for big enlargement factors.

Some simple novel algorithms have been designed to cope with the reconstruction of scanned video data when, due to the wear of the head of the VCR used for recording, some lines appear to be horizontally shifted due to the corrupted synchronization signal. This kind of problems seems to be case specific, compelling us to provide different solutions for different aspects of the same problem. One of the algorithms, for example, estimates the most probable relative position of two neighboring lines by looking at their largest correlation.

Another useful tool realized for MIPE let us perform frame averaging of an object present in different frames and captured under different point of view. Commonly available techniques allow to frame average objects translated parallel to the image plane in consecutive frames, while more advanced algorithms are sensitive to image rotation and rescaling. Our approach is more general and the projective registration tool let us frame...

Figure 1: Screenshot of the proposed Modular Image Processing Environment.

In Fig. 1 a screen shot of the proposed Modular Image Processing Environment is presented as an example.

2.2 Implemented filters and tools

Although still being in a full development stage, MIPE already includes many different tools, either built to deal with typical image processing problems or built to address problems specific of the forensic field. Some operations are implemented through different algorithms, allowing the user to try both standard and more advanced techniques; the latter are mainly based on algorithms already presented to the scientific community (but not generally used in commonly available software) and then adapted or improved to meet our needs. Some other algorithms have been totally developed by us to solve very specific problems.

Besides basic operations like cropping, rotating, flipping and contrast and luminance adjustment, a number of filters have been created for general image processing tasks. In particular, different techniques for image resampling and resizing have been studied and, above the classic nearest, bilinear and bicubic interpolators, some more efficient techniques have been tested and implemented. The resampling algorithms used for image enlargement have then been used for other applications, i.e. correcting the geometric distortion due to wide angle lenses or the perspective effect on an object. Various filters have been implemented to solve other typical problems of digital images such as the presence of noise, the need of sharpening the details and the reduction of blocking artifacts caused by lossy compressions. Also the correction of blur caused by lack of focus or by subject motion has been treated. Some functions are also provided to work with multiple images, calculate their pixel-by-pixel mean and register them correcting small movements of the camera (or the object) or estimate relationships between two images (i.e. signal-to-noise ratio). One of the more interesting feature of MIPE is the presence of a tool for frame averaging several pictures of an object taken from different points of view, thus giving the possibility to obtain some information from a set of even very corrupted images.

Finally, some specific operators have also been implemented to address problems specific of the forensic field. Some various filters have been implemented to solve other typical problems of digital images such as the presence of noise, the need of sharpening the details and the reduction of blocking artifacts caused by lossy compressions. Also the correction of blur caused by lack of focus or by subject motion has been treated. Some functions are also provided to work with multiple images, calculate their pixel-by-pixel mean and register them correcting small movements of the camera (or the object) or estimate relationships between two images (i.e. signal-to-noise ratio). One of the more interesting feature of MIPE is the presence of a tool for frame averaging several pictures of an object taken from different points of view, thus giving the possibility to obtain some information from a set of even very corrupted images.

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average the object of interest (for example a car license plate) even if subjected to different perspectives.

3 EXPERIMENTAL RESULTS

In this section we present some experimental results; in particular, when applicable we compare our results with those obtained with classic image processing techniques and with Adobe Photoshop 7 [15].

As can be seen in Fig. 2, rational interpolation performs somehow better than bicubic interpolation, which is a very common technique and the most advanced interpolation method provided by Photoshop. Iterative application of rational interpolation on test images provides crisper and more defined edges in comparison with the bicubic interpolation, which is affected by blurring effects or jagging artifacts after successive applications. As shown in Tab. 1, numerical simulations, which have been obtained by first 8× undersampling and successive 8× interpolation using several different methods, i.e. nearest (nearest neighbour), bilin. (bilinear), bic. (bicubic), ph.shop (Photoshop bicubic), and rat. (rational), also confirm the effectiveness of the approach.

Rational noise smoothing (see Fig. 3) showed a good improvement in noisy images, avoiding ringing artifacts caused by low-pass filtering or loss of detail typical of averaging filters.

The algorithm to reduce blocking artifacts, typically introduced by lossy compression techniques such as JPEG, led good results (see Fig. 4), smoothing the disturbances while leaving the real edges of the image intact and crisp.

The application of the algorithm for the correction of shifted lines is shown in Fig. 5. It may be noted that the recovery of the image is reasonably good, so that for example the date and time stamp may be easily read.

In Fig. 6 a selection of four frames relative to the rear of a car filmed under different perspective is shown. Each frame has been corrupted by artificial noise thus leading to an unreadable license plate. The projective registration tool permits to make a transformation of the image captured in each frame in order to match a previously defined reference frame, then allowing to obtain a noise reduced version of the object of interest (the license plate in this case) through frame averaging. Even by starting with a set of only five images the tool for registration can provide impressive results as shown in Fig. 7, where the license plate characters are easily readable.

CONCLUSIONS

In this paper a general introduction on forensic image processing and its main issues have been exposed, and an open-source environment for the enhancement of images coming from video-surveillance devices has been proposed.

Principles conducting our work and their practical applications in the attempt to meet as closer as possible the forensic image professional requirements have been
Figure 4: Reduction of blocking effects introduced by JPEG coding: (top) original and (bottom) processed image.

Figure 5: Correction of shifted lines: (top) original and (bottom) processed image.

Figure 6: Projective registration: four images from the original set.

Figure 7: Projective registration: result of frame averaging on transformed images.

depicted. Matlab has been chosen as the development platform thanks to its advanced features, the ease of programming and the possibility to work directly on interpreted functions, making the code visible and easily modifiable, thus obtaining an open to scrutiny software which could better fit legal needs. Some general features of the Modular Image Processing Environment, the software born from this work, have been described and some parts of it have been presented as examples. The implementation of some advanced non-linear operators belonging to the class of filters based on rational functions have been introduced, together with some examples of their effectiveness. We are also evaluating the possibility to switch to a different development environment, probably C++, to overcome the limits of Matlab, in particular in the system memory management and in the creation of
the user interface. However Matlab will almost surely remain the prototyping platform, thanks to the ease of its style of programming and the possibility to write and test rapidly every new algorithm.

The project is currently under development and, together with improving the presented algorithms, we will introduce new bleeding edge operators with the aim to always have the possibility to employ the latest algorithms for image processing tuned to the forensic professionals, in order to obtain what we consider an interesting alternative to available commercial software.

References


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