A SECURITY SYSTEM EMPLOYING EDGE-BASED RASTERSTEREOGRAPHY[¶]

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ABSTRACT

This paper introduces human-face recognition using edge-based rasterstereography, a biometric identification technique employing pattern recognition, which has the potential to be used as identification-based-security system. A raster grid was projected on human face, distortions of which were used to extract curvature information — unique for a face (principal identification and recognition criterion). This information, in coördinate form, was processed by image-processing algorithms. A modified-raster grid was constructed and tested. The modification, mainly, consisted of use of green dots instead of conventional screen composed of stacked squares, which gave acceptable results for green color. Registration, identi-fication and verification were the three phases of face-recognition system proposed by the authors. In the first step, subject's face was captured using a digital camera and stored in the system database. In the second one, the registered face was compared with all the stored faces in the database. The verification phase consisted of comparing the identified face with own stored template. Once the facial image passed these three stages, the face was recognized as the one belonging to a particular individual. Our face-recognition system correctly recognized 190 out of 200 human faces during test runs. This algorithm was computationally efficient and effective. The edge-based-rasterstereographic-face-recognition system seemed to be suitable for identification and security purposes as time and cost-saving mechanism.

Keywords: biometrics, face recognition, stereophotogrammetry, rasterstereography, image processing, security technologies

NOMENCLATURE

2-D	Two-dimensional	P_{12}	Mid-point of P_1 and P_2 in first cell
3-D	Three-dimensional	P_{23}	Mid-point of P_2 and P_3 in the first cell
d	Curve-surface spacing	P_c	Point of intersection
D	Region (square-patch) in which the edges are to be shifted	s	Periodic spacing
		x, y	Generalized coördinates describing the curvature patterns of human faces
G	Gaussian curvature		
I	Binary-edge map	Δx	Change in the x position
κ_1	Fundamental curvature along the horizontal direction	Δy	Change in the y position
		δ	Half-length of the square-patch
κ_2	Fundamental curvature along the vertical direction	Δ	Triangle
		ϕ	$\angle P_{12} P_c P_{23}$ in the triangle $\Delta P_{12} P_c P_{23}$
M	Mean curvature	ϕ_1	Comparison function, which measures point wise match between two images
n	Number of cells		
P_1	Initial point of the first cell	ρ	Radius of arc ($\rho = 1/\kappa$)
P_2	Final point of the first cell		

INTRODUCTION

As the civilization has progressed to provide more comfort and ease of communication and transportation, its offshoots are stresses created by the environment, in the domain of security screening. This is, particularly, true for

airline travel. An awkward or an unusual behavior in the lounge, or of a person, who looks to be too confident or too scared, often, subjects the traveler to extensive screening and search procedures. At times, the name and the profession, accidentally, matches with a person having questionable credentials, which leads to tragic consequences — the graphic case of point-blank shooting on July 22, 2005 at Stockwell Subway Station, South London, because the face of Brazilian Jean Charles de Menezes, closely, resembled with a convicted criminal. Hence, it becomes important to be able to read and process 3-D information of facial features, not only, in terms of height map, as available in moiré pictures, but also, in terms of curvature maps, obtained from rasterstereography, which has the potential to recognize and identify persons from this information.

A person's identity may be recognized in many ways — identity card, signature comparison, fingerprint match, retinal scan, voice recognition, hand geometry, gait pattern and visual recognition of face (Tistarelli and Grosso, 1997).

The subject of face recognition has by and large been formulated as recognizing faces based on the 2D-image captured by a camera. Given an unknown face, the system was required to return an identity based on the known faces in its database. This has evolved over the past 20 years into recognition systems that are fully automatic, taking the image, cropping it, centralizing it, and developing classifiers for successful recognition.

In this paper, we introduce recognition of human faces using edge-based rasterstereography, which is a curvature-analysis technique. The curvature information, in coördinate form, is capable of being processed by image-processing algorithms. A security system is proposed and piloted on the basis of enhanced version of edge-based raster-stereography — use of green dots instead of conventional screen composed of stacked squares. The edge-based-rasterstereographic-face-recognition system, being efficient and effective, can be used as identification system for security purposes. If implemented, this would streamline procedures, where a large number of people have to be processed and allocated to different channels, according to their security rating. The most important application is in airport area, where security screening is, at times, deterring some passengers to use travel, as they find it too intruding and embarrassing.

THE CHALLENGES OF SECURITY SCREENING

The arts and the sciences of security screening is an optimal solution between fare-paying-passenger dignity (privacy and modesty considerations) and the need for a thorough security check. However, the problem is like Russell's paradox in mathematics. If something happens to an airplane because a person was not searched, properly, then there is a legitimate question, why not. If nothing happens, then one would be questioning the legitimacy of a search.

After the 9/11, security hype, which included blatant violations of passenger rights, sensitivities and dignity, for example, from mildly intrusive (hand-held device search of females by male guards in an open area — in the words of a female traveler, "Oh no, that's very weird.") to privacy-violating and humiliating procedures like full-body scans (generating unclothed pictures of passengers, which were, sometimes, viewed by persons of opposite gender and stored in the system) and enhanced pat-downs to the extreme measures of strip-searches in public view (females strip-searched in stairwells at the airport), videotaping of searches (without the knowledge of passenger being stripped) or cutting through shoes of passengers. North-American-civil-rights groups are of the view that such intensive screening violates civil liberties, which include religious freedom, the right to privacy as well as the constitutional protection against unreasonable searches and seizures.

There is a dire need to establish better procedures, which detect and isolate potential threats, at the same time preserve the dignities, the sensitivities and the modesties of individuals by not requiring them to remove articles of clothing (coats, jackets, caps, turbans, socks, *etc.*) or shoes for security measures. This can be accomplished through multi-level screening systems (Kamal *et al.*, 1996*b*) and avoid human exposure to harmful radiation (Kamal, 2010*a*). There are, also, concerns that items passed through the X-ray system become secondary sources of radiation and should not be put back on or held close to body, immediately, after screening.

Requirement for the checks located at the top level are that they should be highly sensitive (very few or no missed cases — AND operator in software development), whereas the checks located at the bottom level need to be highly specific (very few or no false positives — OR operator in software development). The same concept was used in the multi-level screening proposed for scoliosis (Kamal *et al.*, 1996*b*; Kamal *et al.*, 2013*b*) and security (Kamal, 2008*a*).

In fact, the airport security arrangement, which becomes an essential part of smooth operation of airlines, must be streamlined to protect the dignity and the privacy of passengers, at the same time sparing them from privacy invasion and unnecessary discomfiture. Both males and females should be accorded visual privacy (a curtained-off area) for, even, mildly intrusive physical searches (hand-held device, wand, pat-down) of persons. Intrusive pat-

downs of males in an open area, visible to females and children, are, often, embarrassing. CRS Report for (US) Congress accepts this right of travelers, "passengers may opt for screening in a private area" (Elias, 2011). There must be decency and decorum in these procedures. Any type of search of children should be conducted in the presence of a parent (preferably same gender, if available). Permission must be sought before coming near the passenger (for any purpose, when the searcher overlaps the personal space of an *airline-guest* aka *passenger* — hand-held-device searching, questioning, pat-down, wanding), in particular, a child passenger, in which case it should be obtained from caretaker. For a more-intrusive physical search (partial or complete strip-search), a secure area (room with lockable door, offering visual and acoustic privacy, free from audio and video recording devices as well as absence of one-way-viewing arrangements, curtains or sliding doors, behind which other persons could be present, without the knowledge of traveler) is mandatory (at the Pakistani airports, an attempt is made to provide something on these lines for female passengers, although it must be noted that the tent-style enclosure is not providing acoustic privacy) — such a search may, only, be conducted after a search warrant is obtained, in advance, from a judge; airports should make sure that a judge is available 24/7 to grant permission for such procedures, if they become necessary. Passengers should be given the option of requesting a passenger advocate (of the same gender) during the conduct of such procedures. This becomes mandatory, if search of an unaccompanied minor needs to be conducted. In such a case, same-gender representative of a child-protection agency should be present to avoid unnecessary legal tangles, which the security agencies could face at a later stage. All searches should be, properly, documented, which may be required to be produced in courts-of-law, if there arise suspicions of corruption or mishandling of cases.

Physical handling of baggage by the screeners should be avoided at all costs. If needed, it should be conducted in the presence of a passenger advocate. At the Pakistani airports, during the terminal-entrance search of females, it has been reported that searchers are putting their hands in the purses or the handbags, which is very wrong as such practices may lead to stealing of valuables. A better practice for such type of search would be asking the passenger to open the handbag herself (not the screener) and torchlight be shone to look at the contents, without, physically, touching anything. The searcher should be mandated not to distract the traveler through conversation during the process of physical search of belongings, as the later has a right to keep an eye on the process to avoid removal of anything from (or deposition of unauthorized material in) searched baggage. Also, when females go into the tent-style enclosure for pre-boarding physical search of their persons, their purses or handbags (carrying ornaments and cash) are lying on belt hidden from view of the owner, opening up possibilities of theft. By tradition, females are accorded more privacy, when a search of their persons or belongings is conducted. However, it is felt that more is needed as purses or handbags of females are, sometimes, viewed on monitors by male screeners, when they are passed through X-ray scanners. Almost, everyone would agree that a physical search of belongings of female-hand-carry items in the presence of males and children is, extremely, inappropriate. It is, strongly, recommended that, only a female, in a location not accessible to males, should, only, do a physical scrutiny of contents of handbag of another female. Similarly, any type of body scanning of females or children — partial (*e. g.*, face-scanning, finger-printing, iris-scanning) or full (*e. g.*, backscatter-X-ray, emitted-infrared, millimeter-wave, radio-frequency, thermal), with the sole permission to generate and save only data coördinates (x, y, z), not the actual body figure or the shape generated from data-point organization in configuration space. Further, such procedures should be completed, exclusively, by females from the point-of-view of image recording, processing and storing. In order to make sure that physical handling of females and children as well as their hand-carry items is, really, conducted only by females (not the males behind veils), the female officers (one person conducting the procedure, other same-gender-passenger-advocate taking notes — no third official allowed in the area; as such search is to be conducted, individually, not collectively — the third person is supposed to be the traveler, to be searched) conducting procedures (in curtained-off/secure areas, of course), should be mandated to remove veils and show their unveiled photo-identifications prior to the start of encounter, so that the female traveler is certain that she is apprehended by females only.

Presence of male guards or other personnel, during security screening of females, even behind the curtain or behind a monitor in a remote location show the moral turpitude of the society, which fails to protect of honor of her females and children. Such practices are condemned in all mainstream cultures and societies. So is the covert viewing, by males, of pictures of females or children in the name of body scanning or through one-way screen. In fact, females, with martial art and shooting capabilities, these days, are as good as males for the security of searchers. Of course, the same is true (although not felt by many people), when males are violated by prying gazes of strange females in such awkward situations. There is, absolutely, no need for these types of irregularities, as there should be trained male and female staff available at all times in airports to handle tricky situations. The complete gender-segregation suggested in Muslim societies, takes a new meaning in these contexts, as it seems to protect the dignity of both men and women, at the same time reducing the possibilities of rape or statuary rape and avoiding many lawsuits and hearings.
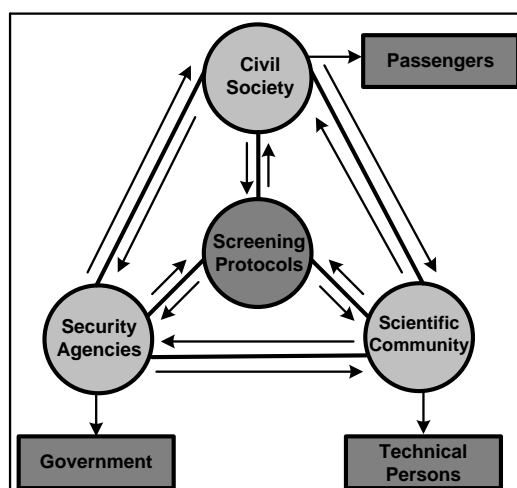
Fig. 1. Stakeholders of screening process, civil society, security agencies and
scientific community (http://www.ngds-ku.org/Papers/J31/Fig_1.htm)

It is, highly, recommended that covert-screening practices should be avoided as they would generate mistrust among the end users and bring in unnecessary lawsuits against the authorities — they are tantamount to corrupt practices and grossly violate fundamental human rights, alerting international organizations, *e. g.*, Transparency International, the Human Rights Watch and the Human Rights Commission. PRESCIENT (2011) report lists different screening methods, some of them covert in their report. Passengers should be given a right to know nature of the security procedures and names of the persons conducting security screening. All staff and officers, who come in contact with the persons and the belongings of passengers must be mandated to display their identification cards, which should bear their recent photographs as well as names in English and local language in a font large enough to be seen from a distance of 5 feet. If any partial or full body scan is conducted, passengers should be able to view all the outputs generated and stored. As per freedom-of-information act, they should be provided copies of the outputs, if they desire so. Such copies may be needed to prepare cases for court hearing.

The airport-search principle: 'Once the passenger is in the secure area, there is no way the traveler can go back and refuse any search procedure deemed appropriate by the authorities', resulting in the graphic and the brutal nature of search procedures, makes an airport not only *a controlled environment* (as given in Wikipedia), but also *a big prison*, stripping a person of essential dignity (by depriving the incumbent of all covering of body) and freedom to move at will. This principle violates human rights, too. Passengers should be treated with respect unless they are proved to be guilty of crimes. 'Innocent, unless proven guilty', must be the guiding principle of all airport searches. There should be 3 secure zones established. Let us consider the example of Jinnah International Airport, Karachi, Pakistan, to understand the security procedures. The first (green zone) is the one just next to the parking area, where the passengers and the visitors are searched through pat-downs/hand-held devices and questioning. The second (yellow zone) is the one, which starts at the entrance to departure lounge before proceeding to the ticket counter — only passengers are allowed after showing valid air ticket, they are searched through security gates and pat-downs/ hand-held devices, whereas their luggage is passed through scanner. The third (red zone) is the one just before boarding the plane, at the airport — where passengers and their cabin baggage is searched like the yellow zone, only the security gates are more sensitive. The airport-search principle, described above, can only be applicable in the red zone, provided passengers are properly informed, written notices (prominently displayed) and repeated verbal announcements, both in English and local language (through color-coded navigational signs in the lounge), that they are about to enter the red zone, where they'll voluntarily give up their fundamental right of freedom from unreasonable search and seizure. In the green zone, the passengers and the visitors are allowed to leave without any questioning. In the yellow zone, the passengers can leave only if the authorities are satisfied after intense questioning that there s no ulterior motive behind the apparent security breach. Even in the red zone, if the security breach discovered does not seem to suggest a terror plot, passengers should be given the option to stop the screening process (and leave the airport area, of course, without using air transportation), if the search turns out to be too intrusive, just like patients have option to ask doctors to stop the examination. Passengers of both genders should be allowed to keep their cabin baggage, often containing cash and valuables, in their possession, while asked to come in a curtained-off/secure area for a physical search, if needed.
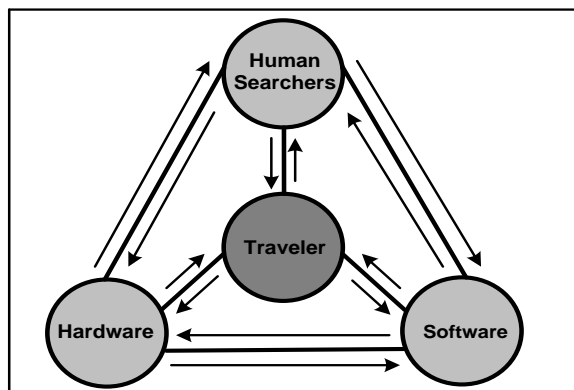
Fig. 2. The search process, 3-way interaction of traveler with searcher, software
and hardware (http://www.ngds-ku.org/Papers/J31/Fig_2.htm)

There should be a code-of-conduct devised for the respectable and the appropriate screening protocols, formulated in consultation with all the stakeholders (Fig. 1) — civil society (representing passengers), security agencies (representing government) and scientific community (representing technical persons). A monitoring agency (which acts independently of the agency responsible for security) should exist to post-review all documented searches conducted in the light of agreed-upon, code-of-conduct, in particular, efficiency, effectives, fairness, human-right protection and humane treatment. There should be an oath of confidentiality to be administered to all persons involved in search of passengers, just like *Hippocratic Oath* required for medical personnel. There must be a thorough background check of those involved in any process of screening, in particular, screening of children. In fact, the last group requires special training in handling children. Screeners must have completed at least first two years of a baccalaureate degree from a recognized university and go through 6 months of intensive training before being allowed to come in contact with passengers or their belongings — when the corresponding author complained to the airport authorities, responsible for security, about inappropriate procedures at the gate, the answer was that an unprofessional might be conducting the procedure. That is alarming, because such untrained persons doing intrusive pat-downs might, even, inflict medical harm to children and elderly travelers. Further, these types of persons could be responsible for security breaches, as they are not capable to recognize threats. There should be freedom from ethnic, religious or appearance profiling, which must include non-discrimination on the basis of color of a person as well as color of one's passport, country of origin, race, faith, political views and disposition towards violation of human rights or exposing corruption — the last 2 become important as the members of international bodies and journalists are harassed at the airports due to what they believe, express and practice. It has been reported that the screeners have, sometimes, intentionally pressed alarms at the security gates and hand-held devices to harass certain travelers. This suggests a more scientific approach of the criteria for intrusive and humiliating screening, which should depend on at least four positive indicators (2 independent machines, 2 blind-scoring humans, who are neither aware of the results of machines nor the judgments of other partners). The search process, therefore, becomes a 3-way interaction (Fig. 2) of traveler with human (searcher), software (program, indicating perceived danger or contraband) and hardware (machine, executing a certain process identifying potential threat or controlled substance). Of course, it would all become very easy for the traveler, the authorities and the civil-society (protecting the rights of passengers), if such search procedures were needed, minimally. This could be possible by better education of prospective travelers by providing them guidelines at the time of booking, through Internet sites, in particular, security-agency site — Airport Security Force (ASF) of Pakistan Army in Pakistan or Transportation Security Administration (TSA) of Department of Homeland Security in USA. Upon arrival at the airport premises, passenger-advocate/security-agency counters may update travelers on the security issues. Passenger advocates may, also, help travelers, who feel that they are treated unfairly during security or custom procedures. The most important prevention of awkward situations, sometimes resulting in embarrassing strip-searches, is a checklist (Kamal, 2013*b*) by the screener of the possible trouble-creating items on person and in clothing, before allowing the passenger to pass through security gate and be subject to hand-held screening. This would save time of screener, passengers and establish better professional relationship between the security-service provider and the end-user. The proposed security-identification system presented in this work, based on rasterstereography, would fit, very nicely, in the current scenario. The passenger presenting on the first security at the Jinnah Terminal at Karachi Airport would be registered by our system, which should generate an identification code. The incumbent's baggage (both cabin and check in) as well as ticket, passport and boarding pass would all be attached to this code and hence, virtually,
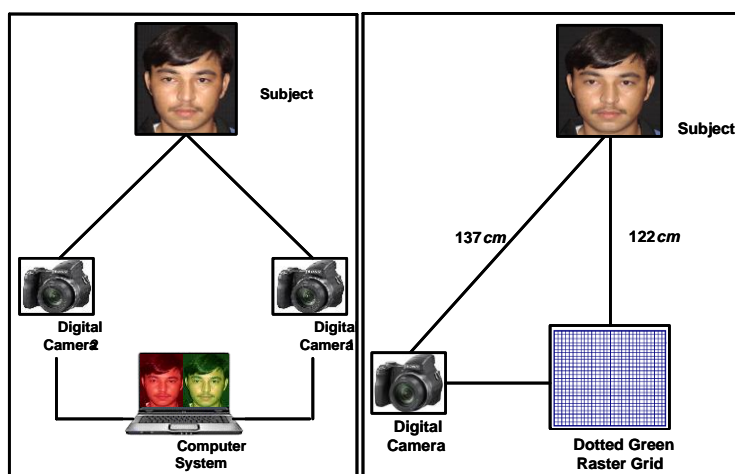
Fig. 3. (*a*) Stereophotogrammetry and (*b*) rasterstereography setups
(http://www.ngds-ku.org/Papers/J31/Fig_3.htm)

tracked. This should become a security enhancement. Anything found on the person and the clothing of a passenger is to be linked to all of the incumbent's personal items and vice versa. On the second security check, this identification could be combined with security rating (stored in a backend file) to facilitate pre-boarding screening. In a report, published last year, US security officials have tried to take measures to respect people's sensitivities (Hanif, 2012). The authors, however, do not feel comfortable with allowing self pat-downs of turbans and *burqas* (an outer garment worn by Muslim females to cover their bodies), as this would compromise security. Given the graphic nature of incidents reported at airports around the world through internet sites and polls, it seems that much more is needed to win back passenger confidence in the institution of security screening.

The quantum physicists, generally, face the challenge of interpreting measurements, where the measurement process, itself, changes the state of a system, thus raising the question about the output of such a process. A similar situation is experienced, when there is a setup of advanced security screening, where the humiliating security procedures, themselves, act as catalysts for average innocent traveler to behave aggressively and, sometimes, subversively, just because the individual's dignity was compromised. That is a very deep question and must be addressed by social scientists and psychologists, together.

Controlled-Substance Detection vs. Identification Systems

The new security paradigm is, gradually, shifting from trace detection (thorough pat-down of each passenger, advanced-full-body scan, canine teams, emitted-infrared radiation to detect explosives or drugs) to ascertaining identity (advanced-face-recognition techniques, fingerprinting, iris-scanning), profiling (background checks based on linkages determined from databases and through NN graphs, intense questioning), stress-level determination (behavior, facial expression, hand manipulation, signature analysis, posture analysis, gait analysis). Kamal (2010*a*) proposed passive-thermal scanning for detection of controlled substances. Some of the new security gate models deployed at airports use this technology. Trusted Traveler Programs, introduced in the near past, are based on background and identification checks. One such program, US Customs and Border Protection's Global Entry, was piloted in 2008 to expedite customs and facilitate domestic-airport screening. These trends strengthen the belief that identification is taking over controlled-substance detection in the new security paradigm. This paper describes curvature-based-face-recognition technique.

STEREOPHOTOGRAMMETRY

Stereophotogrammmtry, a generalization of stereophotography, has its roots in *anthrogeometry* (considered an offshoot of *anthromathematics[a]*)— a branch of mathematics dealing with determining metric of human face[b]. Stereophotogrammetry is a process in which photographs of objects are taken using two cameras, which are overlapped for analysis. It is a singular process, which maps a 3-D-object space to a 2-D-image space, bringing in the concept of dimensional reduction. This process uses standard-light projection to represent height and curvature (3-D) information on a monitor or on a paper (2-D surface) (Fig. 3*a*) — mapping a reimannian surface to a euclidean plane. This technique has applications in areas other than face recognition, *e. g.*, pattern recognition
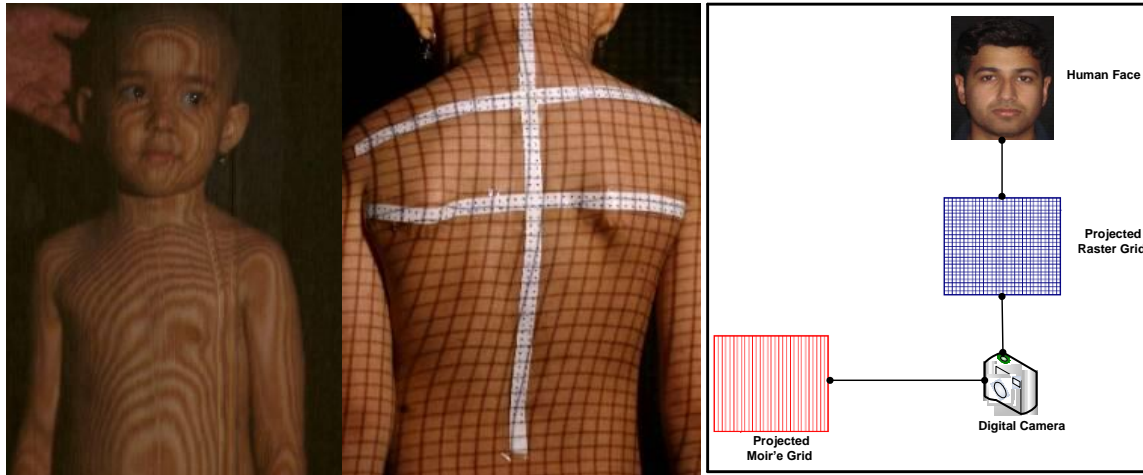
Fig. 4. From left to right, (*a*) moiré fringe topography of a 6-year old, (*b*) conventional rasterstereography of the same child and (*c*) simultaneous-moiré-raster recording using digital camera
(*a*, *b* http://www.ngds-ku.org/photos1/Fig_26.htm, Fig_27.htm)
(*c* http://www.ngds-ku.org/Papers/J31/Fig_4.htm)

(posture analysis), depth analysis (surgical applications, in particular body-surface reconstruction) and movement analysis (gait analysis).

If one of the cameras is replaced by a raster grid imposed on human face through a multimedia projector (Fig. 3*b*), the distortions can be recorded and processed to obtain fundamental curvatures — in the process transforming *passive-scanning* (stereophotogrammetry) to *active-scanning* (rasterstereography) process.

Moiré Fringe Topography

Moiré fringe topography is a height-mapping technique — moiré contours are curves of constant distance from a projected moiré screen (Kamal, 1998). These contours provide height maps, which could be represented as vectors normal to image plane — magnitude of each vector proportional to the height coördinate at that point. These height maps are capable of being handled by image-processing algorithms. Moiré techniques have been applied in the detection (Kamal *et el.*, 1998), the documentation (Kamal, 1982), the quantification (Kamal, 1996*a*) and the follow up (Kamal, 1980) of trunk deformities, in particular, scoliosis (Kamal *et al.*, 2013*b*), posture (Kamal and El-Sayyad, 1981) and gait analyses (Kamal *et al.*, 1996*a*).

Ansari (2008) calibrated shadow-type-moiré frame using a custom-designed wedge. He, then, studied accuracy and precision of moiré-fringe-topography setup in SF-Growth-and-Imaging Laboratory. The models of accuracy and precision (Naseeruddin *et al.*, 1998) were modified and tested for moiré systems — the quantification of height maps was found to be more than 99% accurate and precise. The formulae used to compute accuracy and precision appeared in Kamal (2009*b*). Moiré technique was, subsequently, used to determine body-height maps (Figure 4*a*).

Conventional Rasterstereography

Rasterstereography is, basically, a technique, which can determine local curvatures (Kamal, 2009*a*). One of the cameras is replaced by a light-projection system, which imposes a square-raster grid on human face (Zubairi, 2002). This grid can be generated by periodic extension of basic squares in both the horizontal and the vertical directions, on the pattern of lattice structure in condensed-matter physics (Fig. 3*b*). Upon projection on face, the periodic square becomes an almost-periodic square (the mathematical techniques of almost-periodic functions are required to analyze these patterns). Topological properties of face are hidden in the distorted raster, possibly revealing metric of face. One of the strongest points of this technique is that it does not require a specific arrangement of apparatus to obtain meaningful rasters, whereas specific geometry constrains the moiré setup. Conventional rasterstereography is being applied in the detection of scoliosis (Kamal *et al.*, 2013*a*), documentation of foot problems (Kamal *et al.*, 2011), management of back pain (Kamal, 2008*b*) and gait analysis (Kamal *et al.*, 1996*a*).

Khan (2008) calibrated rasterstereography grids using cuboid, cylinder and sphere. He, then, studied accuracy and precision of rasterstereography setup in SF-Growth-and-Imaging Laboratory — the quantification of curvature maps was found to be more than 99% accurate and precise. Raster technique was, subsequently, used to compute body-curvature maps (Fig. 4*b*).
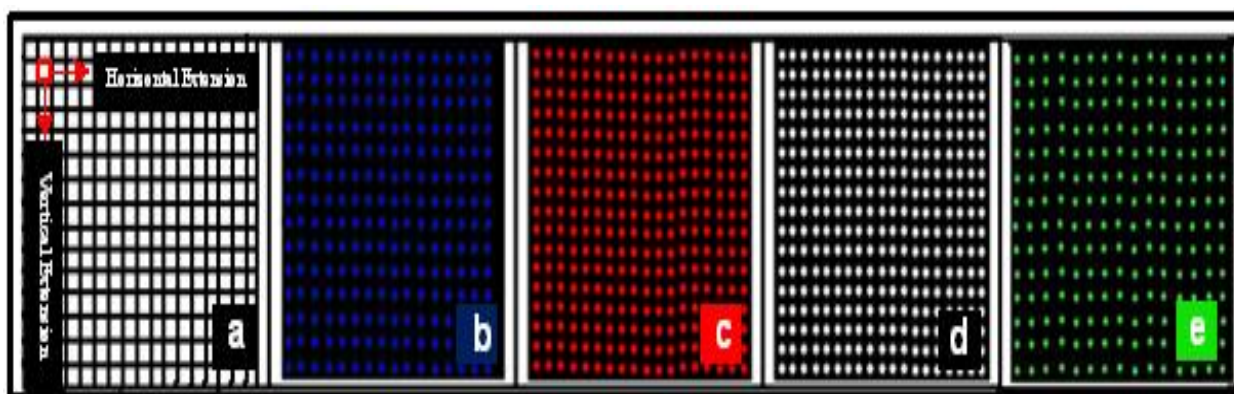
Fig. 5. From conventional to dotted raster — various colored grids tested, best results were obtained in
our lab for the last one, (*a*) repeated-squared-raster grid, (*b*) blue-, (*c*) red-, (*d*) white- and
(*e*) green-dotted-raster grids (http://www.ngds-ku.org/Papers/J31/Fig_5.htm)

Simultaneous Moiré and Raster Recording

For simultaneous moiré and raster recordings one needed a digital camera, 2 multimedia projectors, a moiré grid in red color and a raster grid in blue color (Fig. 4*c*). Both of them were, simultaneously, projected on face. On a color photograph of face, a matching-red filter was placed, which made the red-moiré grid invisible and the blue-raster grid appeared black. These were, then, analyzed using rasterstereography algorithms. A matching-blue filter was placed on the picture. The raster grid was suppressed and the moiré grid appeared black. Later, a standard moiré grid was projected at the same angle, with the same magnification as the distorted grid, to produce moiré fringes. Success of this procedure depended, critically, on proper matching of the colors, which could be improved by reducing bandwidth of the grid colors and the corresponding filters used (Kamal *et al.*, 1996*a*). Recently, 3D-bone scanning was proposed by using simultaneous moiré and raster recording, combined with backscatter-X-ray technology (Kamal, 2013*c*; *d*).

Dotted Rasterstereography

A modified raster[*c*] was constructed, consisting of dots, instead of conventional grid composed of squares (Fig. 5*a*). This new dotted grid minimized the noise effect. Dot positions were easily located, which helped extraction of facial features — dots of different colors were projected on face to find out the best-distorted grid, allowing maximum extraction of information (Fig. 5*b-e*). The authors were motivated by work of Wu and Lee (2012), who devised reversible-data-hiding method using images of different colors. A dark room was needed to record dotted-curvature patterns of faces. Specifications of our setup are given in Table 1.

EDGE-BASED ALGORITHM

Edge-based algorithm is a parallel-motion algorithm (Fig. 6*a*) for computing the optical flow (Little and Bulthöff, 1987). This algorithm is motivated by Veto Scheme (Fig. 6*b*), which is based on voting for consistent motion (Bulthöff, 1988). The physical constraints on motion, uniqueness (no two lines cross each other) and continuity (lines do not break), limit optical variation of the flow field (Fig. 6*c*), which is assumed to be locally uniform (interline spacing is same). If the surfaces are locally smooth, then the flow is differentiable, in addition to being continuous. Correct motion is identified by all points in the neighborhood of a feature (nearest-neighbor-interaction concept in solid-state physics) and voting (Fig. 6*d*) conducted for motion. A flow chart is included to summarize key steps in the construction of this algorithm.

Edge-based Moiré

Edge-based moiré is a combination of edge-based algorithm and moiré pattern (Kamal, 1996*b*). These patterns are supposed to change if the object starts performing infinitesimal movements towards or away from the observer. For example, facial moiré patterns of a person would start moving, if that person utters a single word or a sentence. Infinitesimal motion (to be analyzed by infinitesimal transformations) of lips away from (towards) the observer would result in converging (diverging) of the patterns, corresponding to a sink (source) field. The moiré patterns, therefore, replicate the effect of a convex (concave) lens.

Table 1. Parameters for dotted-rasterstereography setup

Layout	Distance (cm)
Between the subject and the multimedia projector:	122
Between the subject and the digital camera:	137

Fig. 6. Clockwise from top left, (*a*) parallel-motion algorithm (for computing optical flow), (*b*) edge-based VMA (voting-motion algorithm), (*c*) computation of optical flow and (*d*) the first step of computation elaborated (http://www.ngds-ku.org/Papers/J31/Fig_6.htm)

Edge-based Raster

A combination of edge-based algorithm and raster pattern, edge-based raster is a method to quantify infinitesimal curvature changes in the facial pattern of a person, when the contours of face change, because of micro-level movements (*e. g.*, due to change in facial expressions or speaking). The edge-based algorithms developed to handle raster patterns have the capability to process mesa-level facial (gestures indicating approval or denial — rotation of face about transverse and longitudinal axes, respectively) movements. The changing raster patterns (new and old) could be connected by edge-based algorithm and curvature change could be represented as a vector field. In this paper, the edge-based raster, conceptually introduced in (Kamal, 2008*a*), is coded and implemented in the face-recognition module.

FACE-RECOGNITION TECHNIQUES

The face-recognition process can be visualized as registering of signals from face (distorted-dotted-raster points), conversion into data set (point extraction and coördinate values) and subsequent extraction of (curvature) information (Figure 7). This information is converted into knowledge in two different ways — face-recognition module, to be handled by computer systems (software-image interface, which recognizes a face by matching mean
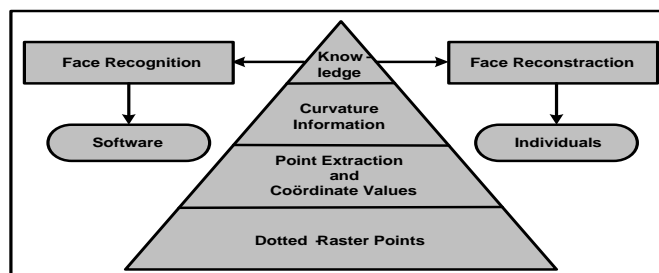

Fig. 7. Face-recognition and face-reconstruction modules (http://www.ngds-ku.org/Papers/J31/Fig_7.htm)

and guassian curvatures of a face, without looking at the actual face) and face-reconstruction module, information to be represented by computers and interpreted by humans (human-image interface, in which human operators use their observation, pattern-recognition skills and sixth sense to recognize faces).

The face-recognition techniques may be divided into two classes — face-based and constituent-based (Lai *et al.,* 2000). Face-based approach consists of capturing and defining the face as a whole (global approach). In the constituent-based approach, recognition is by identifying relationship between human facial features and face boundary. These techniques are discussed below**:**

Holistic Approach

In the holistic-face-recognition approach, global information from face is used (Lam and Yan, 1998). The faces are, commonly, used in eigen-pictures for matching (Zhao *et al.*, 2003), recognized as a whole, influenced, not just, by facial features, but also, by facial expressions, layout of the features and their relationship to one another. The different sequential stages of holistic-face recognition method are facial analysis, activation of templates, collection of personal-identity information and, finally, retrieval of name. The advantages of holistic approach are the capability of, distinctly, capturing the most prominent features within facial images in order to, uniquely, identify individuals amongst a gallery (universal) set. By a suitable algorithm, features could be, automatically, determined. The disadvantages of the holistic approach are that the image characteristics may vary because of changes in orientation (of the equipment), positioning (of the subject), lighting conditions, gestures and scale (Khan *et al.*, 2011). Further, features appearing to correspond to a face may not form part of the face under consideration, but some other features captured. For example, the algorithm may capture features from the background and not the face region. Lighting-condition problems may be handled by enhancing image contrast through three-level-adaptive-inverse-hyperbolic-tangent algorithm proposed by Yu *et al.* (2013).

Feature-Based Approach

Feature-based approach is the structural-matching method (Manjunath *et al.*, 1992). In this method, local features of human face (eyes, nose and mouth) are, first, extracted and their locations are, then, stored in a file for
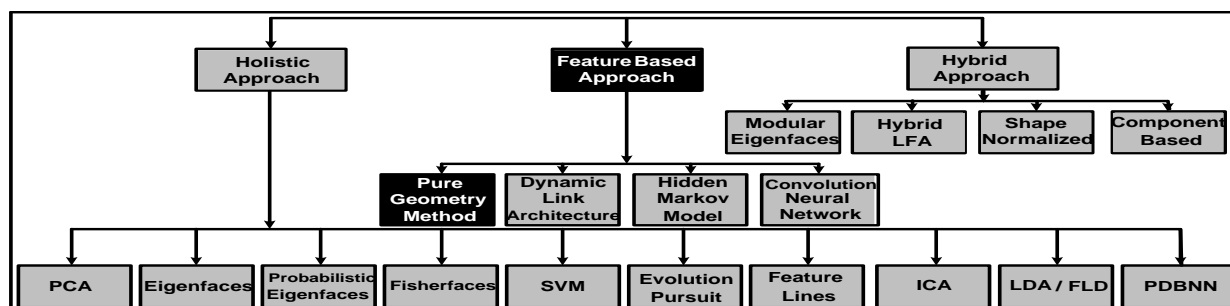

Fig. 8. Categorization of face-recognition techniques
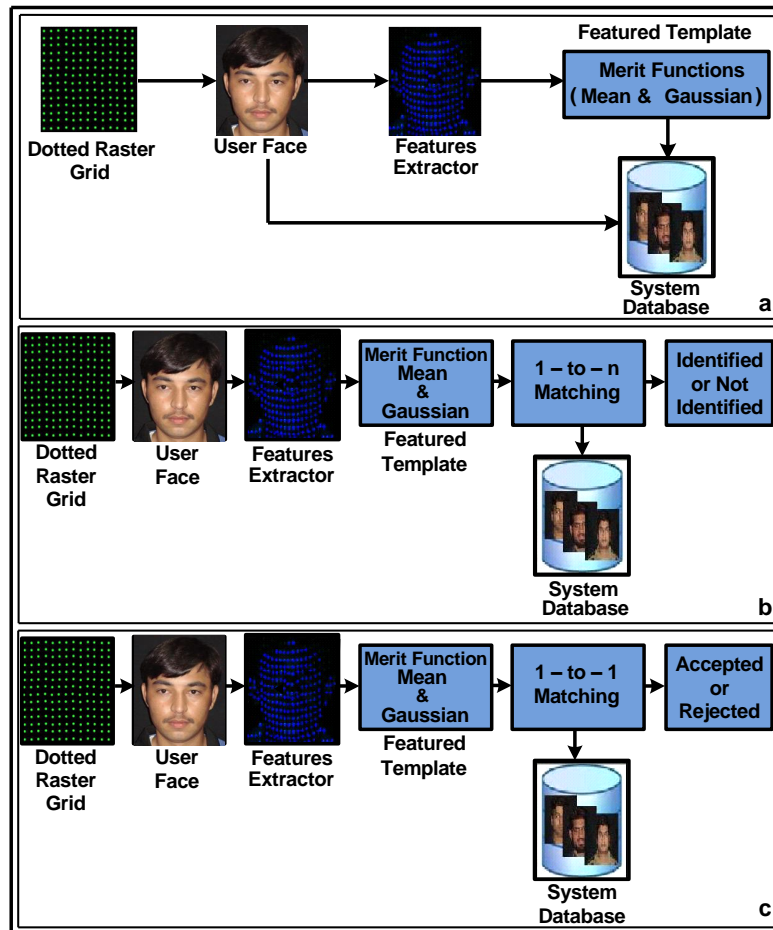(http://www.ngds-ku.org/Papers/J31/Fig_8.htm)

Fig. 9. Steps in face recognition, (*a*) registration, (*b*) identification and (*c*) verification (http://www.ngds-ku.org/Papers/J31/Fig_9.htm)

further processing (Fig. 8). The advantages of feature-based approach are accurate selection of facial features to, exclusively, identify individuals and robustness in detection performance despite facial-expression variations — faces being shadowed by another object, orientation, positioning or lighting. There are the disadvantages of this approach, too. If the features are selected manually, this may introduce human bias in the selection process. On the other hand, if features are selected automatically, the selection process may be dependent on the accuracy of feature-based approach employed.

Face Recognition using Dotted-Raster Grid

This is the main contribution of this paper. The face-recognition module consists of projecting dotted raster on human face, recording of distorted raster containing local-curvature information, point extraction, analysis, encoding/decoding and recognition of face. This system used dotted raster, which was an improvement over conventional square-grid raster, in which traversing of line was difficult. Such a traversing was needed to detect crossover points. A further benefit of dotted raster was that the points were easy to pick. The shortcomings of the holistic approach — sensitivity to changes in orientation, positioning, lighting conditions, gestures and scale — have been, partially, resolved in our approach. All the selection processes are automated and reproducible.

RASTERSEREOGRAPHY-BASED-FACE-RECOGNITION SYSTEM

The face-recognition system, described in this work, is divided into three stages, registration, identification and verification (Chan, 2008). In our software-development process, registration was the first stage (Rad and Atani, 2012), followed by identification and verification.

Fig. 10. Raster pattern projected on the human face in different positions
(http://www.ngds-ku.org/Papers/J31/Fig_10.htm)

Registration

The subject first registered in the system database to be authenticated for later stages of the process. For this purpose, the incumbent's facial image was, first, captured using a digital camera and stored in the database. Each image was assigned a specific ID for authentication purpose. Dotted-raster grids were used to extract the distinguishable facial features and stored in form of an array (Fig. 9*a*). Featured template of the subject was constructed on the basis of mean (*M*) and gaussian (*G*) curvatures. These curvatures were generated from the fundamental curvatures, κ_1 and κ_2, where $\kappa = 1/\rho$, the symbol ρ represented radius of the fundamental circle, using the relations, $M = \dfrac{\kappa_1 + \kappa_2}{2}$ and $G = \kappa_1\kappa_2$ (*cf.* Appendix A).

Identification

The developed application compared a captured image with the registered faces (stored templates of users from the system database) to determine, whether our system was able to identify the person or not (Fig. 9*b*). For this purpose, the system compared the selected template with all the available templates in the database to find an exact match. The system made a template-match and, subsequently, identified the face or it failed to make a face-match. One-to-many comparison was, therefore, needed to find a true relation (Jafri and Arabnia, 2009).

Verification

In the final stage, our application verified and authenticated a person's identity by comparing captured image with own respective template stored in the system database (Fig. 9*c*). Since the system compared the captured face with template of the same person (stored in the database), one-to-one comparison was employed to recognize the respective face.

METHODOLOGY

The dotted-rasterstereography setup used in our laboratories was portable. One needed a multimedia projector (lens of focal-length range: 24.3 *mm* − 29.2 *mm*), a dotted-raster grid (with 0.6 mm inter-dot spacing) and an advanced-digital camera (10 mega-pixels). This grid was imposed through the projector on human faces of subjects. The curvature patterns of a human face, with different orientations, were recorded using a digital camera and stored in the system database (Fig. 10). Facial image was divided into pixels and pixel-coördinate values were extracted (Fig. 11). The methodology of face recognition may be summarized in the following modules, each module dependent on the preceding one (Fig. 12).

12	*19*	*30*	*…….*	*157*	*(140.50, 247.80)*	*(144.12, 257.59)*	*..*
08	*20*	*31*	*…….*	*150*	*(157.16, 247.17)*	*(163.50, 257.20)*	*..*
.	*.*	*.*	*.*	*.*	*.*	*.*	*.*
.	*.*	*.*	*.*	*.*	*.*	*.*	*.*
.	*.*	*.*	*.*	*.*	*.*	*.*	*.*
18	*29*	*40*	*…….*	*160*	*(285.50, 368.00)*	*(281.37, 379.00)*	*..*

Fig. 11. From left to right, face (to be recognized), face pixels, pixel-coördinate values
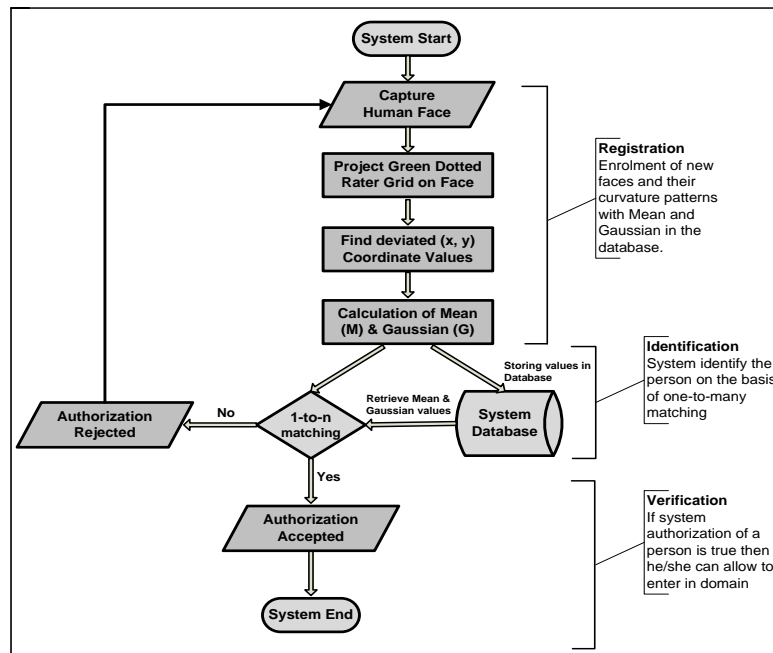(http://www.ngds-ku.org/Papers/J31/Fig_11.htm)

Fig. 12. Flow chart of rasterstereography-based-face-recognition system
(http://www.ngds-ku.org/Papers/J31/Fig_12.htm)

Point Extraction

The point-extraction module consisted of grid projection on human face, subsequent distortion, sharpening of points, extraction of facial features, which resulted in grid elimination (Figure 13*a*).

Analysis

The analysis module took output of the point-extraction module as input, isolated data, eliminated anomalies (outliers), reduced noise and cropped the image, which generated a normalized image (Figure 13*b*).

Encoding/Decoding

The encoding/decoding module took output of the analysis module as input, generated coördinates (x, y) based on facial geometry (facial geometry is reimannian, not euclidean), calculated curvatures (mean and gaussian), which were stored as outputs (Figure 13*c*).

Recognition

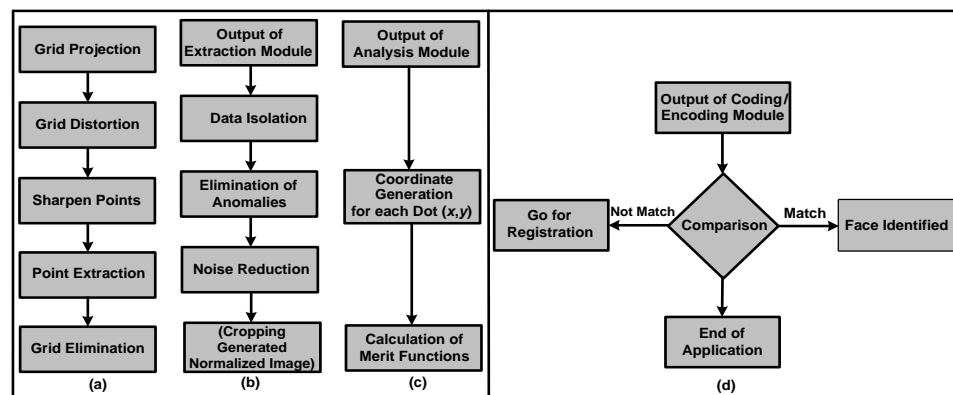The recognition module took output of the encoding/decoding module as input and compared with the set of

Fig. 13. Steps of face recognition using edge-based rasterstereography, (*a*) extraction module,
(*b*) analysis module, (*c*) coding/encoding module and (*d*) recognition module
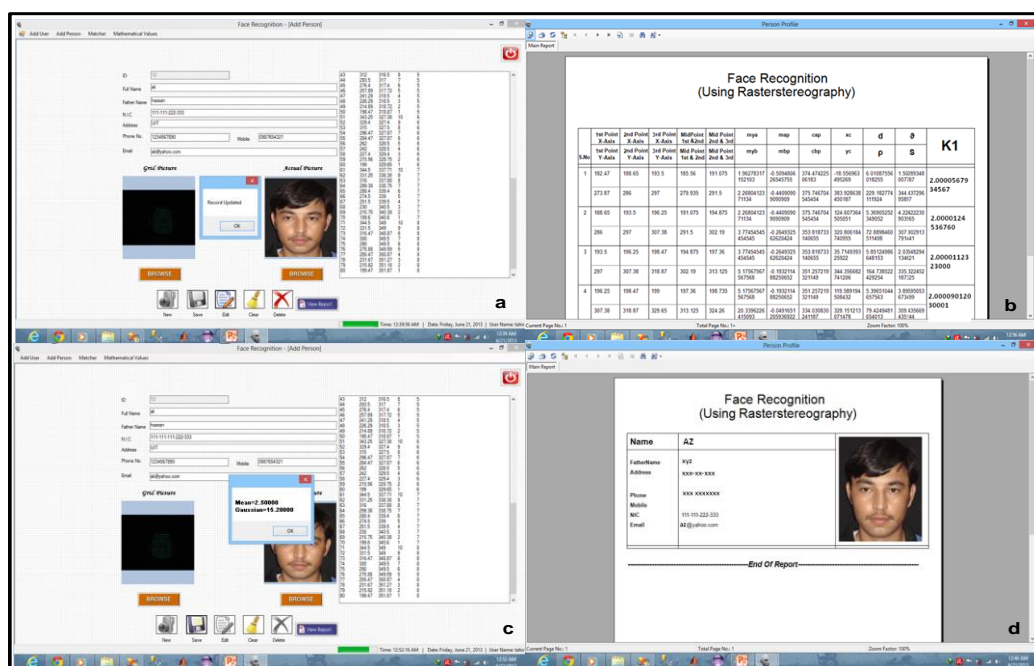(http://www.ngds-ku.org/Papers/J31/Fig_13.htm)

Fig. 14. Screenshots of software, (a) addition of subject in the system database, (b) calculation of curvatures,
(c) calculation of mean + gaussian and (d) generation of profile of subject
(http://www.ngds-ku.org/Papers/J31/Fig_14.htm)

stored faces. If a match was found, the face was identified. Otherwise, the person was instructed to go for registration (Figure 13*d*). Mathematical basis is described in Appendix A and formulae are derived in Appendix B.

RESULTS

Figure 14 gives the screenshots of the software used to process the image. Average values of mean and gaussian curvatures of subject with ID 12, were calculated as 2.5 cm^{-1} and 15.2 cm^{-1}, respectively, which formed the bases of recognition. These values were found independent of gestures and facial rotations (5 positions — frontal, ± 5 degrees about longitudinal as well as transverse axis). The system was, also, able to recognize bearded faces, mustached faces and faces with glasses. The face-recognition technique, described in this work, was tested on 200 faces, which included both genders (age range: 16-20 years); 95% faces were, correctly, recognized. An upper bound of 45 second per image was estimated to process one face. The results are summarized in Table 2.

DISCUSSION AND CONCLUSION

The face-recognition system described in this work employed multimedia-light-reflecting technology, which was portable and easy-to-setup. Further, the system was found to be accurate during test runs. For this purpose the pixel information with their corresponding pixel-coördinate values had to be generated from the distorted grid of face of the test subject and added in the system database. These coördinate values were used to calculate the horizontal and the vertical curvatures. Mean and gaussian curvatures were obtained and stored along with the original face of the subject. A unique ID was generated for each individual for the purpose of identification and recognition. Once, the subject was recognized, the system generated a report, having the profile of that subject.

Table 2. Parameters for dotted-rasterstereography setup

Description of Parameters	Numerical Value
Total number of faces registered in the system database	800
Number of faces tested using edge-based-rasterstereography software	200
Number of faces recognized correctly	190
Number of faces recognized incorrectly	10
Accuracy (ability to correctly identify faces) of the system	95%

This system was found to be safe, convenient and decent (no unclothed images of body were generated and stored). Also, such a system was cost effective. We did not find any hazards to human body, as all procedures and sub-procedures were non-contact — no infection or germ transfer (no biological material involved), non-invasive — no ionizing radiation involved (in contrast to full-body scan, which involves backscatter-X rays) and non-destructive (in contrast to wand or pat-down, which may hurt or damage wounds). This technique did not use potentially hazardous laser beam (iris-scanning requires laser-beam sweep, which may, permanently, damage eyeball, if the beam intensity and characteristics go wayward). Also, there was no chemical spray involved (fingerprinting requires spraying the body-part to record patterns — sometimes, the operator, accidentally, sprays the fluid in the eyes of incumbent, which could cause damage to the eyeball). In addition, these procedures do not cause any pain or discomfort, when implemented on human subjects. These features render them most suitable for biometric identi-fication systems as well as medical diagnosis and treatment.

Convenience (short processing time), which is a measure of efficiency, was one remarkable feature of this setup. This system, therefore, seemed to have the potential to be used as the prime security and identification system in the near future. The authors envision an open-source-data-collection-and-handling environment, where data centers have a virtualization link. The open-source software, being a knowledge-based product, reuse oriented, incrementally developed and infinitely replicable, is free, but the people are not — those who invest their time and energy in developing the software would recover back their efforts through consultation fees. It is hoped that face-recognition systems, like the one presented in this work, bring out efficiency, effectiveness, decency and reliability in airport search procedures as well as form the essential identification component of cardless authorization and charge system proposed earlier (Kamal *et al.*, 2012).

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APPENDIX A: MATHEMATICAL BASIS

Linear spacing between two consecutive dots on the reference-grid surface was denoted by *s*. When grid was projected on a face, distorted-curvature pattern was generated. The curved surface generated an angular spacing between two consecutive dots, denoted by *d* (Fig. 15*a*). This curved surface under study was considered part of a
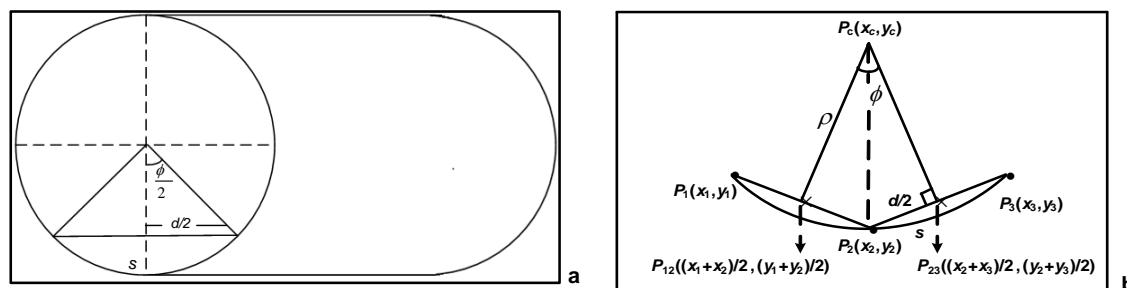

Fig. 15. Mathematics of rastersthereography, (*a*) geometrical analysis on the
base of a right-circular cylinder and (*b*) calculation of the first cell
(*a* http://www.ngds-ku.org/Papers/J31/Fig_15A.htm)
(*b* http://www.ngds-ku.org/Papers/J31/Fig_15B.htm)

circle, whose radius was ρ (Kamal, 2008a). The fundamental curvatures (κ_1, κ_2) gave mean (M) and guassian (G) values, which were used to differentiate curvature patterns among different human faces. These two parameters were solved for cells 1 to n ($n = 120$, on the average).

APPENDIX B: DERIVATION OF MATHEMATICAL FORMULAE

Coördinate values of the first cell were written in terms of (x, y). The midpoints P_{12} and P_{23} were computed for the sets of data-points $\{P_1(x_1, y_1), P_2(x_2, y_2)\}$ and $\{P_2(x_2, y_2), P_3(x_3, y_3)\}$. Angle was computed by considering the triangle $\Delta P_2 P_{23} P_c$ (Figure 15b)

(A1)
$$\sin\frac{\phi}{2} = \frac{d/2}{\rho}$$

Solving equation (A1) for value of d and expanding $sin\frac{\phi}{2}$ using binomial expansion, one got

$$d = 2\rho\sin\frac{\phi}{2} = 2\rho\sum_{n=0}^{\infty}(-1)^n\frac{1}{(2n+1)!}\left(\frac{\phi}{2}\right)^{2n+1}$$

Using $\phi = \kappa s$ (noting that $s = \rho\phi$ and $\kappa = \frac{1}{\rho}$), the right-hand-side of the equation was expanded as

(A2)
$$\frac{d}{s} = 1 - \frac{1}{3!}\frac{\kappa^2 s^2}{4^1} + \frac{1}{5!}\frac{\kappa^4 s^4}{4^2} - \frac{1}{7!}\frac{\kappa^6 s^6}{4^3} + \ldots \approx 1 - \frac{1}{3!}\frac{\kappa^2 s^2}{4}$$

Extreme-right-hand side was written by retaining only the first two terms in the series, dropping the fourth- and the higher-power terms. It was a reasonable approximation, as terms of the above series represented a monotonically-decreasing sequence — κs being very small compared to the first term in brackets, which was unity. Solving (A2) for κ, one obtained

(A3)
$$\kappa \approx \pm\frac{1}{s}\sqrt{24\left(1 - \frac{d}{s}\right)}$$

For the horizontal and the vertical cells, curvatures were denoted by κ_1 and κ_2, respectively. Sign convention was adopted such that positive sign represented convexity, whereas negative sign denoted concavity.

ENDNOTES

[a]*Anthromathematics* (mathematics of body sizes, forms, proportions and structures) was introduced on March 22, 2010 (Kamal, 2010a). *The First Conference on Anthromathematics* was organized by Department of Mathematics, University of Karachi on September 4, 5, 2013:
http://www.ngds-ku.org/Anthrmathematics/Anthromathematics2013.pdf
[b]*Anthrogeometry* was first used on April 10, 2013, during a research seminar held at the Federal Urdu University of Arts, Sciences and Technologies (Kamal, 2013a).
[c]The concept of using dots instead of squares to construct the raster grid is attributed to AB. It has resulted in marked improvement in capabilities of extracting facial features.

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