DNA as a Biometric Identifier

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DNA, a biometric?

DNA differs from standard biometrics in several ways:

- DNA requires a tangible physical sample as opposed to an impression, image, or recording.
- DNA matching is not done in real-time, and currently not all stages of comparison are automated.
- DNA matching does not employ templates or feature extraction, but rather represents the comparison of actual samples.
Why DNA?

• DNA is unique to every individual on the planet
  – Only identical twins share the same DNA
• It can be easily obtained from a variety of sources
• It is readily used in forensics to match crime scene evidence to individuals
• It does not change during the life!
DNA Sources

- Paper or plastic cup
- Glass
- Ear wax
- Fingernail clippings
- Socks
- Urine
- Licked stamps
- Cheek swabs
- Sweaty t-shirts
- Hair with roots
- Hair without roots
- Dried blood
- Whole blood
- Chewed gum
- Dental floss
- Cigarette butts
- Used tissue
- Dried skin
- Used razor
- Other biological specimens
DNA Basics
Think back to high school biology!
• Double-stranded helical molecule resembling a twisted ladder
• Sugar and phosphate backbone and nucleic acid interior
• Found in the nucleus of all cells (there is also DNA in the mitochondria of cells)
• Bundled into chromosomes
• Chromosomes replicate each time a cell divides
DNA Basic (con’t)

• Only 4 nucleic acids (nucleotides) comprise the genetic code of DNA
  – (A)denine
  – (C)ytosine
  – (T)hymine
  – (G)uanine

• Base Pairing! A-T and G-C

• 3 billion such the pairs in DNA

http://www.don-lindsay-archive.org/creation/dna.jpg
During replication, the two DNA strands separate, or denature, and a new complementary strand is constructed using the exposed bases as a template!
Human DNA

- Humans have 23 homologous ("pairs of") chromosomes resulting in 46 total
  - One set of 23 from each parent is passed on to offspring.
  - 99.7% of human DNA is shared.
  - 0.3% (~ 1 million nucleotides) is variable!
  - This variability is inherited and is therefore unique to each individual.
  - These variable regions, called Short Tandem Repeats (or STRs), can be examined to distinguish one person from another.
STRs (Short Tandem Repeats)

• In order to distinguish one person from another using DNA, you need highly variable segments of DNA.
• In the early 1980s, several highly variable regions were discovered that could be used to tell individuals apart!
• Today, there are 13 such regions that are used in DNA profiling.
How do STRs work?

• At each of the 13 regions (or loci), there is a repeated sequence that is variable in length between individuals.
  – ACCT repeated at one locus, or TTTC repeated at another
• The number of repeats at each location can be measured during DNA sequencing.
• Each number of repeats has statistics associated with it that can be compared to the population.
• The Product Rule can be used to multiply the statistics for all 13 regions, yielding a highly individualizing result.
• Most DNA profiles give odds of sharing a profile with another person on earth as about one in a trillion!
Example STR result for a single locus
13 CODIS Core STR Loci with Chromosomal Positions

- TPOX
- D3S1358
- D5S818
- FGA
- CSF1PO
- D8S1179
- D7S820
- TH01
- VWA
- D13S317
- D16S539
- D18S51
- D21S11
- AMEL
- AMEL

Chromosomes 1 to 22 and X, Y
Cracking the DNA code!

3 Important Steps:

• Extract (obtain and isolate DNA from sample)
• Amplify (create multiple copies of the “target sequences”)
• Sequence (obtain unique code of nucleic acid bases from the DNA sample)

***Contamination at any of these steps will result in test failure!!!***
DNA Extraction

Main Methods of Extraction:

- Organic
- Chelex™
- FTA™ paper (or similar)
- Alkaline
DNA Extraction Methods

• Organic
  – Uses a phenol, chloroform, and several centrifuge steps to separate DNA from cellular debris.
  – Time: 2-3 hours

• Chelex™
  – Uses a boiling step and iminodiacetic beads to bind DNA.
  – Quick, but also not very clean and prone to degradation
  – Time: less than one hour
DNA Extraction Methods (con’t)

- **FTA™ paper**
  - Sample placed directly on paper, allowed to dry, and is washed several times.
  - Paper can then proceed directly to amplification reaction.
  - Time: less than an hour

- **Alkaline**
  - Sample is dissolved in a strong base such as sodium hydroxide and the DNA is removed via filtering
  - Time: several hours
DNA Amplification

• After DNA is isolated from a biological sample, the number of copies must be increased
• DNA must be amplified before proper sequencing can be carried out to ensure enough is present for the reaction
Polymerase Chain Reaction (PCR)

- PCR is an enzymatic amplification of DNA.
- PCR exponentially increases the initial copy number of DNA.
- The reaction requires extracted DNA, primers, a polymerase (the enzyme), free-floating nucleotide bases, and buffer.
- These ingredients, along with a series of temperature increases and decreases, allows for rapid, accurate replication of DNA.
- TIME: 2-3 hours for 32 cycles
Polymerase Chain Reaction

1. A DNA molecule with a target sequence to be copied is heated to denature it.
2. When the mixture cools, primers bond to the single-stranded DNA.
3. dNTPs and DNA polymerase are added to synthesize two new strands of DNA.
4. The process is repeated, doubling the amount of DNA.
5. By repeating the process, many copies of the original DNA can be produced in a short time.

http://bcs.whfreeman.com/thelifewire/content/chp11/fl1020.gif
DNA Sequencing

• DNA sequencing is the step that generates a DNA profile.
• Amplified DNA is loaded into the genetic analyzer (sequencer) with fluorescently labeled A, T, C, and Gs attached to the DNA.
• An electric current is applied to the system and the DNA migrates past a laser—the bases that pass by the laser are recorded, one at a time, until the entire sequence is recorded.
• Once the data are analyzed, a unique DNA profile can be visualized.
• TIME: ~30 minutes per sample
Common Genetic Analyzers

ABI 310

Hitachi FMBIO II

http://www.appliedbiosystems.com/catalog/myab/StoreCatalog/products/CategoryDetails.jsp?hierarchyID=102&category1st=a50&category2nd=a51&category3rd=111903

http://www.helixxtec.com/Hitachi/fmbio.htm
DNA Profiling Timeline

- Obtaining a sample such as a swab of cheek cells (buccal swab): ~10 seconds
- Extracting DNA: 30 minutes – 3 hours
- Amplifying DNA: 2 – 3 hours
- Sequencing DNA: 30 min – 1 hour

Total: \textit{minimum} of approximately 3 hours

This is unacceptable for biometric use! What can be done??
Advances in DNA Technology

- Extracting DNA
  - New commercial products are available that allow for the rapid collection and extraction of DNA
  - The Bode Technologies Buccal DNA Collector functions similarly to FTA™ paper
  - A scraping of cheek cells can be collected and transferred directly to the PCR reaction tube for amplification, greatly reducing extraction time

TIME: less than 30 seconds
Advances in DNA Technology

• Amplifying DNA
  – Products in the research stage can amplify DNA in minutes rather than hours!
  – The new devices rapidly change temperature, allowing DNA to be copied at a much quicker rate
  – **MATCI (Miniature Analytical Thermal Cycling Instrument)** is a portable PCR unit that can perform 32 cycles in about 21 minutes!
  – On-chip PCR utilizes glass microchips with sample chambers to perform PCR
  
**TIME:** approximately 20 minutes
MATCI device

Advances in DNA Technology

• Sequencing DNA
  – High-throughput DNA analysis is commercially available with products like the ABI 3730xl.
  – Microchip sequencers in the research phase have small channels etched in them that perform the DNA separation and laser detection.
  – The small distance (~2cm) the DNA travels (opposed to 35cm in standard machines) allows results in as little as 30 seconds
  – High-throughput microchips have also been shown to provide results up to 5 times faster than current machines (Paegel et al.)
ABI 3730xl

http://www.appliedbiosystems.com/catalog/myab/StoreCatalog/products/CategoryDetails.jsp?hierarchyID=102&category1st=a50&category2nd=a51&category3rd=111907

Nanochip™ Microchip

Advances in DNA Technology

- New research in microchip technology is aiming to combine DNA amplification and sequencing!
- Adding DNA extraction to the continuous flow microchip is also in the works
- Combining all three steps to obtain a DNA profile is the DNA profiling method of the future, and the one that is most applicable to biometrics
Timeline with new technology

- Obtaining a sample such as a swab of cheek cells (buccal swab): 10 seconds
- Extracting DNA: ~10 seconds
- Amplifying DNA: ~20 minutes
- Sequencing DNA: 30 seconds – 5 minutes

Total: Less than 30 minutes!
Matching DNA Profiles

- CODIS
  - The CODIS System currently in place by the FBI is similar to AFIS
  - Convicted offenders’ DNA profiles are loaded into the system to catch repeat offenders and those that commit crimes across state lines
  - Simple matching is the algorithm used to compare profiles
  - A database such as CODIS would be ideal for a biometric DNA database
To Summarize...

- DNA is highly individualizing and has great potential as a biometric identifier
- The nature of DNA and the state of current technology prevents DNA from being an efficient biometric
- New technology and current research have greatly reduced the time required to generate a DNA profile
- Despite the current advances, DNA profiling as a means of biometric identification still falls short of current demand