Disability-Friendly Biometric Systems: A Way to Make Biometrics More Inclusive

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ABSTRACT

In this paper, we will discuss the pre-existing concerns of accessibility and inclusivity related to biometrics. Accessibility problems and disability bias breed biometric technologies that are not user-friendly for all consumers. This paper will also propose design changes that can be implemented to increase the overall inclusivity and accessibility of these systems, such as allowing users to choose from multiple biometric methods within one system. The paper will also examine specific disabilities and the appropriate systems to address users with these disabilities. An example of one such disability is blindness and its effect on the accuracy and execution of iris and retina scans. By adding other ways of getting past the authentication process, such as scanning the sclera instead, we are putting a more accessible and inclusive system in place. Additionally, this paper will highlight case studies with real-world examples. We aim to bring attention to human and machine bias towards impaired individuals and suggest possible solutions to increase inclusivity within the field of biometrics.

KEYWORDS: Disability, accessibility, inclusivity, disability bias, unconscious bias, bias audits, contactless fingerprinting, false acceptance rate, false rejection rate, false negative identification rate

I. Introduction

The development and implementation of biometric technology and systems are rapidly advancing with each passing day. Biometrics are predominantly used in systems that serve the purpose of identification or verification. Inclusivity and accessibility are crucial to making these systems fair and equitable for all individuals to use. There must be a focus on creating disability-friendly interfaces when engineering biometric technologies. Engineers are forming developments to address these concerns and progress is being made. However, research suggests that significant barriers remain in making any data-driven biometric system more accessible for people with disabilities or impairments. Assumptions in the development of these technologies can lead to issues with accessibility even if certain legal requirements are met. The datasets that are used to train many biometric systems are also inherently biased because they rarely take into account the full demographics of their user base.

The existence and constant evolution of biometric technology creates greater opportunities for individuals with disabilities just by its nature. A user with Parkinson’s disease might struggle to enter a traditional password or PIN but can still log into a device or account using a biometric system like facial recognition. Perhaps another user is born with Phocomelia, a rare birth defect that results in missing limbs, and is incapable of using the keyboard on their phone or computer. A biometric system using voice recognition could allow the individual to still have full access and control over their device.

However, there are still more steps to be taken to improve the overall friendliness of biometric systems when it comes to users with disabilities. Biases, whether deliberate or unconscious, need to be eliminated in the design and development process of these biometric technologies to create more impartial and fair systems for all to use. The examination of the accessibility of biometric technologies is vital as these systems become more commonplace in our everyday lives.

It is imperative to have a firm grasp and understanding of the disabilities that our user base might face and a concrete definition of what the term “disability” even means. The World Health Organization defined the word as, “Any restriction or lack of ability to perform an activity in the manner or within the range considered normal for a human being.” However, in 2001, the definition was changed to that of the International Classification of Functioning, Disability, and Health, identifying disabilities as “complex social and physical interactions between an individual, activity, society, and environment.” (Wobbrock, 2018). Setting a concrete precedent on the idea of disabilities in this way allows engineers to have a better understanding of all the potential needs of the users of the systems they are developing. This also allows for the inherent disability bias that exists within the engineering process of biometrics to subside.

II. Disability Bias

a. *Bias in Biometrics*

These problems that present themselves in biometric systems for disabled users are a direct result of an internalized disability bias, both in data and development. Biases exist in every part of daily life. Oftentimes, these biases are unconscious in nature. According to the University of California San Francisco, unconscious biases are defined as “social stereotypes about certain groups of people that individuals form outside their own conscious awareness.” (Navarro, n.d.). Conscious biases still exist and can cause the design and development of technologies, facilities, tools, and much more to be inequitable for specific groups of people. However, explicit biases like these are far less common than they once were. More often than not, the biases causing these issues end up being implicit or unconscious. “Unconscious bias is far more prevalent than conscious prejudice and often incompatible with one's conscious values. Certain scenarios can activate unconscious attitudes and beliefs.” (Navarro, n.d.).

There are a multitude of reasons why unconscious biases may present themselves in one’s work. Under less-than-ideal circumstances, these biases can become far more prevalent. For example, time constraints and high-pressure work environments can lead to a lack of consideration of certain specialized groups, implicitly biasing the design process. In the field of biometrics, this can be especially common. There are so many different types of disabilities, injuries, and ailments that can affect individuals that it is difficult to take them all into consideration. Even if engineers and developers who are working on a given biometric system bring attention to inclusivity and accessibility in their work, it is highly unlikely that all types of users will be considered.

A related concern for any data-driven biometric system is that the data sets that are used to train these models are inherently biased as well. The data rarely ever has a comprehensive understanding or representation of the extent of users the system may encounter. Many physical disabilities are far more common than others. Additionally, some individuals may have multiple impairments. Addressing the biases that result from this is not as simple as just increasing the number of categories. “Impairment is not static, homogenous, nor do people only have one impairment. One person may have many impairments with synergistic effects. For example, facial recognition is less successful for older adults with dementia.” (Taati, 2019). Furthermore, not everyone experiences the same type of disability the same way. Blindness and its physical impact on the person who is affected by it will vary from one individual to another. No two people will experience Parkinson’s Disease the same way. These impairments are also subject to change over time. As a person gets older, the severity and physical impact of the disability may increase as a result. Ensuring that collected data is as broad as possible is incredibly important. It is not as simple as whether a person has a certain disability or not. Data sets need to include as much context as possible, considering multiple impairments over different stages of life instead of just assuming that these experiences with disabilities are fixed and static.

b. Addressing Biases

To be able to properly address the biases that exist within the development of biometric systems and the data sets that drive them, appropriate assessment methods that can uncover these biases need to be used. “Aggregate metrics can hide performance problems in under-represented groups.” (Besmira, 2018). Aggregate metrics in biometrics are performance measures that give us an idea of how well the system or technology works for all users or across all data points. Although this method can efficiently summarize a biometric system's effectiveness, it does not consider some crucial information. Aggregate metrics are used to combine data collected from all user groups into a single data set. However, the problem arises from the fact that the aggregate metric is an average of these numbers. The results the system developers receive may show high performance and accuracy because marginalized group data makes up the minority and will not have a significant impact on this average. To combat this, performance metrics should be disaggregated. Performance metrics such as false acceptance rate (FAR) and false rejection rate (FRR) can be disaggregated to help analyze if a biometric system is performing any differently across particular groups. Metrics across all types of different demographics should be monitored. These measured values can then be compared to the average to determine any significant differences.

Many other steps can and should be taken to minimize and eliminate biases in biometric technologies. Major leaders in technology and machine learning development, such as Google and IBM, have already created accurate bias detection tools. Implementing these third-party tools into the development and data analyzing biometric processes can help to ensure that fewer explicit and implicit biases remain present. After implementation, these detection methods should be tested by purposefully introducing biases into the work and data to see if they are detected. The potential for biases should continue being monitored even after the system is up and running. The performance metrics should continue being tracked by whatever means necessary to zone in on biases across certain demographic groups in real-time. Bias audits should also be conducted regularly on the system. A bias audit is defined as “a targeted, non-comprehensive approach focused on assessing algorithmic systems for bias.” (Groves, 2023). In the case of biometrics, bias audits can consist of bringing in several independent experts to analyze the datasets and processes involved in the system.

III. Accessibility Problems

a. Preliminary Issues

A study by Shaun Kane, a computer science professor and researcher at the University of Colorado Boulder, surveyed 40 participants with disabilities and their specific experiences with biometric systems. The survey takers noted a handful of issues they faced with biometric sensors such as: *“premature timeouts, poor positioning, being “invisible,” mismatched range of motion, variability of abilities, setup difficulties, biometric failures, security vulnerabilities, incorrect inferences, and data validation problems.”* (Kane, 2020). These are all very general issues that persist in biometric systems used all over the world. However, there are more specific types of biometrics that individuals with certain disabilities will have a more difficult time using for a plethora of reasons.

Another study conducted by the Centre for the Recovery of Persons with Physical Disability of Madrid (CRMF) gathered 41 subjects to test the accessibility of certain systems and technologies. 21 of these subjects claimed and showed some form of disability while the other 20 did not. These 20 individuals served as the control for this experiment. *Figure 1* shows the makeup of the test subjects in the study along with a breakdown into specific groups for each type of disability. These groups consisted of people with hand or arm disabilities (HAD), leg disabilities (LED), visual disabilities (VID), and cognitive or learning difficulties (CLD). *Figures 2* and *3* show the results in terms of percentages of verification errors for three different biometric methods. *Figure 2* focuses on fingerprinting while *Figure 3* focuses on facial recognition.

	CRMF	Control
Gender	14 males / 7 females	10 males / 10 females
Age	12 (18–30) 5 (31–45) 4 (46–60)	6 (18–30) 8 (31–45) 4 (46–60) 2 (61+)
Academic degree	8 Univ. degree 5 High school 7 Primary studies 1 No studies	12 Univ. degree 5 High school 3 Primary studies
Experience	18 Mobile devices 10 Computers 2 Biometrics	20 Mobile devices 15 Computers 5 Biometrics
Groups	5 HAD*1 11 LED*2 2 VID*3 17 CLD*4	

*1HAD: Hands/arms disabilities,
*2LED: legs disabilities,
*3VID: Visual disabilities,
*4CLD: Cognitive/learning difficulties

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Figure 1: Breakdown of CRMF test subjects

Test Subjects		Session
		Visit 1
CRMF	HAD	0%
	LED	9%
	VID	0%
	CLD	0%
Control		0%

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Figure 2: Percentage of fingerprint verification errors

Test Subjects		Session	
		Visit 1	Visit 2
CRMF	HAD	11,7%	25%
	LED	24%	41,8%
	VID	40%	80%
	CLD	11,76%	30,58%
Control		24%	25%

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Figure 3: Percentage of facial recognition errors

b. Fingerprint Scans

Fingerprint scanning is one of the most commonly used biometric methods. It has been used as early as the 1880s, initially for identifying criminals and for signature use. Despite its longstanding history, fingerprint scanning systems still lack the necessary accessibility features in their development and implementation. According to the U.S. Department of Veterans Affairs, “There are around

500,000 (Americans) who have lost one or more fingers. While there are many prostheses available for people without hands, far fewer exist for people with finger loss." Further, individuals with severe burning, scarring, or other hand or finger injuries will struggle to use fingerprinting technology. These systems are also less accessible for users suffering from neurological disorders that affect their ability to use their hands, such as Parkinson's Disease, cerebral palsy, and Huntington's Disease. Fingerprint scanners are used extremely commonly these days in practical applications such as smartphones and financial institutions and their subsidiaries. Therefore, it is critical to consider these affected users when designing fingerprinting biometric methods and applying them to daily systems.

c. *Iris and Retina Scans*

Eye scans are also very common, specifically for recognition and authentication purposes. Retinal scanning was invented in 1935 while iris scanning came later in the 20th Century. Issues with biometric technologies also present themselves when used by individuals affected by blindness. Iris and retina scanning are common types of recognition and authentication methods involving the eyes. Oftentimes, these types of scans do not work consistently when attempted by blind users. These parts of the eye, particularly the iris, can be damaged or corrupted to the point where these biometric scans will not work. According to the World Health Organization, "Globally, an estimated 40 to 45 million people are blind and 135 million have low vision." This is a significant number of potential users who may not be able to use a biometric system or technology at all because of issues with their iris or retina.

d. *Facial Recognition*

Facial recognition systems were also developed and put in place in the late 20th Century. They were also originally used in tandem with fingerprinting in the field of law enforcement. A few decades later, real-time recognition was made possible with the development of facial detection technology. Facial recognition scans typically have low accuracy to begin with. Additionally, these scans are heavily affected by external factors, particularly facial trauma. This may include cuts, bruises, scars, and burns, just to name a few. Individuals with these types of physical issues will have increased difficulty using facial recognition technologies. Some users may also have missing or partially missing key facial features such as noses, eyes, and ears. All of these facial characteristics work in accordance with one another to increase the reliability, accuracy, and ease of use of the facial recognition system. This will also create challenges with the success of the facial scans.

IV. Proposed Solutions

a. *General Solutions*

We can see that large groups of people are affected by specific birth defects, disabilities, injuries, or ailments that may prevent them from using a particular type of biometric technology. Every biometric system should have at least two methods of verification and identification. We have already started seeing this on a basic level in smart devices. Many new-generation smartphones and tablets have implemented the use of facial recognition on top of the already existing fingerprint scanning method. This allows for a user who is incapable of using fingerprint scanning to use facial recognition to access their device instead, and vice versa. The main concern with this proposition is the financial drawback on the side of the business or company. Introducing another method and system will increase the overall cost of the product and that company's expenses. However, these costs may end up being nearly negligible as the increased accessibility will also lead to a larger potential user base and hence, more people purchasing the products.

However, there are some other downsides to this solution. Adding more authentication and verification methods will affect the overall robustness of the biometric system in question. It will increase the system's complexity, creating new challenges in ensuring that everything works together seamlessly and potentially introducing new points of failure. Each type of biometric has its own error rates. One system may have a higher FAR and lower FRR, or any other combination of these rates. Joining multiple of these methods can skew the error-handling ability of the systems. One method may falsely accept an illegitimate user trying to get into the system while another correctly rejects that same user. Some biometric types are easier to get accepted by. This subsequently also poses security risks. For example, maybe a user is correctly rejected from accessing a smartphone by trying to scan their fingerprint. The same user is then falsely accepted by the same device's secondary biometric method, facial recognition. This false user has now gained access to a device that is not their own.

These challenges, although significant, can be counteracted with more careful system design. The importance of inclusivity and availability for all users should ultimately outweigh the problems that are created as a result of adding an additional biometric method. The final goal should be to create a well-balanced system that provides opportunities for more people without compromising accuracy or security. To accomplish this engineers and developers should focus on making these biometric systems more adaptive. Authentication based on user needs can be implemented into the system. For example, if the disability or ailment is a temporary one, the system can switch to a more suitable method. If an individual has trouble using their hands, such as temporary bone breaks, the system can recognize this and switch to another method of verification like voice recognition for the time being. For more permanent injuries and disabilities, the biometric system can create user-tailored profiles. User preferences will be stored and this will allow for a system to quickly and effectively choose the best biometric method available based on each user's specific needs.

b. Fingerprinting Solutions

Changes, both large and small, can be made to fingerprint scanners to increase their overall accessibility and inclusivity without compromising anything significant. Higher-resolution scanners can help in situations where the users have partial fingerprints or minor scarring or burns to their fingers. The higher-resolution scans will produce more detailed images to counteract the damage to one's prints. The standard resolution for the average fingerprint scanner is about 500 pixels per inch (PPI). However, some systems and applications use scanners that generate image scans of upwards of 1000 PPI. These scanners are generally less common and used frequently in forensics, government agencies, and high-security facilities. Although it may not be practical to integrate 1000 PPI fingerprint scanners in more common, daily applications, scanners that produce images with resolutions greater than 500 PPI should still be considered. A system that produces scans of 700 to 800 PPI resolution would serve as a significant upgrade over the standard and help create more detailed captures of the user's fingerprint minutiae.

Contactless fingerprint scanners have been applied in systems before and are becoming more common each day. Eliminating the need for physical contact with the scanner increases the ease of use for potential users who have limited mobility and dexterity, particularly with their hands. These types of scanners also tend to have a wider range of angles to scan incoming fingerprints. This will also help increase accessibility for individuals who may struggle to fully align one or multiple of their fingers on a traditional scanner. In 2019, The National Institute of Standards and Technology (NIST) conducted a study to determine the effectiveness of multiple commercially available fingerprint scanners. The study found that devices requiring physical contact were generally superior in terms of matching scanned prints to images within a database. However, the discrepancy on this front was made up by using contactless devices that scanned multiple fingerprints at the same time on one hand to show improved performance. "For contactless devices, particularly smartphone applications, optimizing for focus and lighting of index and middle fingers should produce the best results." (Libert, 2019). *Figure 4* shows the improved performance of two-finger contactless law enforcement (LE) and commercial (COM) scanners in terms of FNIR.

There are not many options outside of the proposed general solutions that can increase accessibility for individuals with missing appendages. One possible solution would be to install prosthetic finger registration within fingerprint scanners. This would of course have to work in collaboration with a user having or getting prosthetic finger replacements where necessary. Fingerprint scanners can be trained similarly to how they already are to start detecting and recognizing prosthetic fingers and their respective prints. In doing so, they may then be able to authenticate a user based on the specific patterns and materials of the prosthetic part.

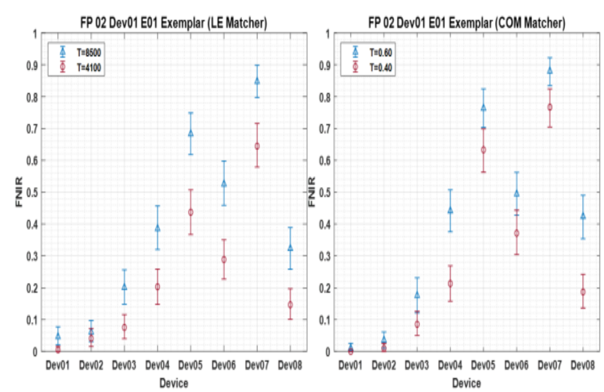

Figure 4: False-Negative-Identification Rates across eight law enforcement devices and eight commercial matcher devices for two-finger contactless scans

c. *Iris and Retina Solutions*

Some broad implementations can be made on biometric systems to increase their accessibility for users with eye problems. Many of these solutions can be seen in other applications around society. For example, individuals suffering from blindness or other vision impairments will have a difficult time using the biometric technology at all. To combat this, developers and engineers can add multimodal assistance to the technology. Voice assistance along with haptic cues and feedback will help ensure these types of affected users can still follow along with the necessary biometric authentication process.

Changes should be made to the overall design of iris and retina scanners. For instance, these scanners should have an adjustable range of motion. A scanner with changeable height will be accessible to more people, particularly those in wheelchairs or with difficulty standing up straight. This will be an inexpensive addition that will serve to allow more users the ability to use eye-scanning services. Adding a wider capture area for the eye scans could also prove beneficial. This would give the systems more flexibility in capturing images for individuals who have potential mobility concerns or impairments that may otherwise prevent them from successfully scanning.

Biometric systems involving the human eye can scan the sclera instead of the iris or retina. The sclera is the white outer layer of the eyeball which is the protective covering of the human eye. Iris and retina scans can be particularly difficult for users affected by partial or complete blindness. “In the case that the person is blind and the eye is open, and the blindness affects both iris and retina and both are corrupted or not useful in the authentication process, then the best solution for this problem is using sclera for identifying and authenticating blind person.” (Ahmed, 2017). This is because the sclera has blood vessel structures that are unique to each individual. Sclera scanning consists of obtaining a user’s eyeprint, similar to a fingerprint, using these blood vessels. The sclera’s blood vessel structure can be remotely and non-intrusively obtained through visible wavelengths. The sclera also does not depend on eye power which means that it can effectively be used as a recognition method for individuals without eyesight. If the user is blind or suffering from a damaged iris and retina, image acquisition will still work on the sclera. The structure of the sclera’s blood vessels is visible and stable over long periods which makes this method an adequate replacement for iris and retina identification scans.

d. Facial Recognition Solutions

Facial recognition systems already suffer from issues with accuracy due to many external factors. Most smartphones use 2D facial recognition which can cause both security concerns and problems with accessibility. The use of a 3D facial recognition system instead would eliminate these concerns. This type of technology would allow the capture of the full depth and contours of an individual's face. In turn, this would make the scans more reliable and accurate for users who might have physical damage or other variations within their faces. Additionally, certain features are less likely to be missing or affected by some sort of trauma. Using 3D scans and focusing on these more robust facial features such as the unique structure of the user’s face should help reduce some of the accessibility problems. Researchers at the University of Notre Dame conducted an experiment to compare the effectiveness of 2D versus 3D facial scans. The experiment probed datasets of 200 subjects that were imaged using both 2D and 3D methods. “Using a PCA-based approach tuned separately for 2D and for 3D, we find that 3D outperforms 2D.” (Chang, 2003).

Customizable settings can also serve to increase accessibility in facial recognition systems. For non-covert systems where the individual is using facial recognition themselves, settings can be included to adjust lighting, contrast, scan sensitivity, and more factors. These changes could lead to improved scan accuracy and account for users with facial conditions or damage. For more covert systems where a user would not be able to personally adjust settings, algorithms can be implemented to accomplish the same thing. Engineers can develop dynamic algorithms to automatically adjust the scanner's settings based on the success rate of scans and the detection of potential facial anomalies. Training these systems to recognize scars, burns, missing features, or any other type of facial trauma can lead to improved accuracy and subsequently, increased accessibility.

V. Conclusions

Biometric systems inherently create more accessibility for individuals with disabilities or impairments. A user may not be able to use traditional verification processes like PINs and passwords but the option to use biometric methods such as fingerprint and facial recognition scanning gives them more opportunities. However, inclusivity and further accessibility are still a concern in biometrics. The various studies based on subjects with disabilities throughout this paper indicate this to be true. Many individuals have stated having an assortment of issues using biometric technologies depending on what disability they have. Additionally, the success rate of certain systems can be seen to differ based on what users are afflicted with.

Disability biases, predominantly unconscious but also explicit ones, are one reason why these issues persist in biometrics. Data sets that are used in the development of these systems often do not adequately reflect comprehensively inclusive demographics. These biases can be combated by disaggregating performance metrics like FAR and FRR in the analysis of a system. The use of bias detection tools and implementation of bias audits, along with consistent monitoring of potential biases, can also help eliminate these problems.

Inclusivity and accessibility are issues that can be evident in any biometric system. Fingerprinting, eye scanning, and facial recognition technologies in particular were focused on. Each of these biometric methods has its own set of challenges when used by individuals with disabilities. Users with neurological disorders, missing appendages, or other damage such as cuts and burns will have a difficult time accessing fingerprinting technology. Higher-resolution scanners, contactless fingerprinting, and the addition of prosthetic finger scanning can help reduce these issues and increase accessibility. Individuals suffering from blindness or any other kind of damage to the eye may struggle to use traditional iris or retina systems. A scanner with adjustable height that also has voice assistance and haptic feedback will make it much easier for these types of people to use. The use of sclera scanners in place of the more common iris and retina scanners will also increase the overall accessibility of this type of system. Facial recognition technologies can be difficult to use for individuals affected by any form of facial trauma. Using 3D face scanners, focusing on robust facial features, and having adjustable scanner settings can help alleviate issues with facial recognition technology.

Although biometrics help increase accessibility in verification and identification systems, there is still a long way to go. Studies conducted by major institutions and researchers are evidence of that. The reduction of disability bias in the data collection and development process of these systems is crucial to ensuring that they are more inclusive of marginalized groups and accessible to all parties. Furthermore, implementing additional biometric methods without sacrificing too much will give disabled users more options. The application of specific solutions for each biometric type will also increase the accessibility of the systems they are in. The goal is to propose and potentially use these solutions in biometrics. This, along with the elimination of disability bias in the developmental stages, will greatly increase the accessibility of many biometric systems and create a more equitable, comfortable, and inclusive space for all potential users.

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