Virtual Reality Assessment of Usability and Ergonomics in Hand Vein Biometric Systems

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***Abstract*—Vein pattern recognition is a relatively new biometric technique that has gained recognition and traction in the last years. Still, for active researchers of this domain, one of the problems that can be identified is the lack of end-user feedback regarding the usability and ergonomics of proposed biometric scanners. In addition, touch-free scanners introduce more issues regarding the pose and postures of users interacting with a biometric device. With the recent advent of virtual reality devices and motion capture systems, large scale tests can be conducted with commercially available packages at a fraction of the price and resource allocation of a real-life usability study. This paper aims to give an insight into the practical implementation of a virtual reality study applied to biometric usability and attempts to offer a possible roadmap where these technologies are complementing behavioral experiments in biometrics.**

Keywords-vein patterns; biometric recognition; virtual reality; motion capture; inertial sensors.

I. INTRODUCTION

Vein pattern recognition is a biometric technique that has gained significant traction in the last decade. Mostly employed on the hand area, common blood vessels for visual extraction are the veins in the back of the hand, palm, forearm or fingers [1][2]. While the underlying science is thoroughly understood, the technology has rarely left the confines of academic research and there are few mainstream applications, usually from large industrial players [3][4].

As a long time research interest of the authors, vein biometrics, especially the veins in the back of the hand, have been analyzed and described in various scientific papers [5-9]. As a direct result of the research, several hardware devices and software algorithms have been devised by the authors for this biometric parameter. New sensing topics, such as unconstrained hand acquisition scenarios; posture, pose and angle of attack for users presenting biometric data and general ergonomics have also been recently discussed [10][11].

The underlying problem is represented by the lack of information regarding user preference -posture and ergonomics- and the degree of usability that a biometric system might have. There is little feedback in the creation of new hardware devices except for the intrinsic technical prowess of a newer prototype. A full-scale experiment involving several tangible mockup devices, where subjects are filmed on location interacting with the biometric systems is difficult to implement due to higher cost and required post-analysis. In addition, changes to real devices in order to account for the ongoing experimental data is difficult to achieve. Even small scale adjustments such as angle of positioning or distance between sensing elements and hand position are challenges for a real hardware device.

Virtual reality has advanced significantly in the last 5 years and commercially available headsets exhibit sufficient resolution and tracking speed for such an experiment. The participants' movements are tracked in real time while using virtual assets and exploring false environments. This technology transposes easily to behavioral data, biometric systems' assessment being a valid use case with no significant prior work being identified by the authors during the state of the art research.

Since the procedure used to acquire the veins of the hand in biometric systems is most often contactless [3]10], there are palpable advantages when using a virtual reality device. In an unconstrained hand scenario, the lack of physical objects to interact with increases immersion since there is no disconnect between what the user sees and feels. In addition, most users unconsciously refuse to walk through solid objects or touch objects that are undesirable to be touched in the real world [12].

With the help of a secondary inertial system, experiments have been carried out related to biometric presentation using free hand rotation with sub-millimeter tracking accuracy on various hand angles on all axes. Also, ergonomic data has been recorded and analyzed for future hardware implementations.

After the introduction in Section 1, Section 2 presents the experimental setup mentioned earlier and Section 3 unveils the experiments that were perform for the virtual reality usability study. The conclusions of the article are depicted in Section 3.

II. EXPERIMENTAL SETUP

The experimental setup consists of a combination of several consumer level technologies. The general availability of these systems and devices, together with the reduced pricing, allows for reproducible virtual reality research due to early standardization efforts.

The Virtual Reality System chosen for this research is an Oculus Rift CV1 comprised of a headset, hand controllers and external reference cameras for position tracking [13][14]. Orientation tracking is performed using the integrated inertial sensors and the drift is corrected every 20ms by the reference infrared cameras providing a tracking accuracy of 0.5mm and a display refresh rate of 90Hz. The experimental setup involved the placement of four cameras in opposing corners denoting a movable testing space of 3.5 x 3.5m.

Figure 1. Virtual Reality station and reference sensors. The steering wheel and throttle and stick levers are not used in this particular set of experiments but they are employed for other behavioral studies using virtual reality in biomedical applications.

The Virtual Reality station can be observed in Figure 1 and the tracking area in Figure 2. Figure 1 also reveals other hardware devices used to monitor behavior and posture in multiple biomedical use-cases (intoxicated driving, day – night cycles for workers etc.)

The users of the system can move freely in the designated area; the only inconvenience is the headset cord (carrying video and sensor data) that can get tangled around the user.

A complete untethered package has also been created with the use of an older Oculus headset, the Developer Kit 2. Due to the reduced computational requirements, the headset has been paired with a laptop carried by the user for the duration of the experiments. While this technique has provided substantial data regarding user behavior, the reduced resolution and diminished moving space have been detrimental to the immersion level. The decision has been made to use the powerful but tethered modern system.

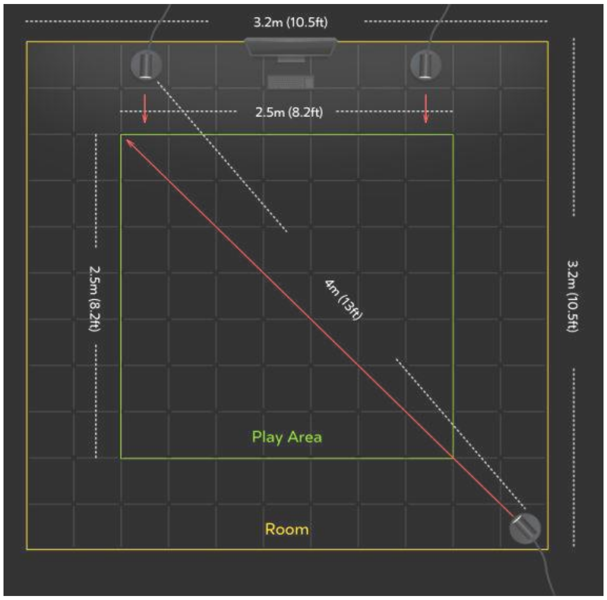

Figure 2. Area trackable by the Oculus Rift headset. [15].

Since the system is only able to distinguish position and orientation of the head and the hands, an extra hardware package has been employed for full body orientation acquisition. The secondary system is a Perception Neuron motion capture suit with 32 individual nodes called “neurons” [16]. Each node is a 9 Degree of Freedom (DoF) sensor (tri-axis accelerometer, gyroscope and magnetometer) that relays the orientation data to a central hub for further processing. Using inverse kinematics and considering the rigid model of the human body, fine movements of the limbs and body can be sensed. Due to the placement of nodes on the fingers of the hand, accurate orientation and position of the user’s hand can be inferred, allowing the system to gather sensor data for the main battery of experiments related to usability in hand vein biometrics.

The conforming elastic glove, the active sensing elements and the connections to the central hub are shown in Figure 3.

The glove has 9 sensors capable of detecting minute movements of the hand and fingers in all axes and, due to the inclusion of two extra sensors on the wrist and forearm, the relative angles between the torso and the hands are correctly measured.

The stream of data is very stable if the user has the feet planted on the ground, as the system has a robust detection algorithm based on the fixed position of two neurons on the upper plantar area if the user is not moving. However, being an inertial system with no frame of reference, it is very susceptible to drift if the user displaces the feet from the ground either by walking or jumping.

In order to accurately track body stances and dynamic behavior -while allowing the subjects to move freely- both systems are needed. The difficulty in processing the data from two separate tracking entities arises from the mismatch between the coordinate systems. In addition, the Oculus Rift headset is tracked at the head level while the center node for the Perception Neuron Suit is situated in the middle of the body.

Figure 3. Perception Neuron inertial glove, sensing elements and connections.

Two approaches have been identified and implemented during the experimental phase:

- Fusing the sensor data from the Oculus Rift CV1 with the orientation information gathered from the Perception Neuron suit -using the head as a base node in the kinematics chain.
- Using the Oculus Rift hand controllers- since they are not needed on the hands if the motion capture gloves are employed- rigidly attached to the back and front of the body at the height of the original primary node of the suit.

While both solutions allow the data to be unified for further processing, using the head as a primary node creates additional tracking inaccuracies. This is in part due to the increased number of joints from the head node to the feet and several user poses will allow excessive drift to accumulate over short periods of time.

Using the touch controllers preserves the original point of reference for the inertial suit while offering the same level of accuracy provided by the Rift headset. Employing both hand controllers – while slightly adding difficulty to the pose estimation- offers a higher degree of resistance against optical occlusion, a four-sensor setup detects the position of one or both of the controllers at all positions inside the testing area.

This provides one complete solution for full body tracking in a virtual world with added emphasis on the hand and fingers.

Simulations have been created using Epic Unreal Engine, a photorealistic graphics engine. Asset geometry data has been devised and rendered in Autodesk 3dStudio Max including all the virtual objects, biometric scanners and environments, subsequently being imported in Unreal Engine.

Creating a virtual asset is significantly less expensive and time consuming than creating a real asset. In addition, the use of virtual reality provides multiple scenarios, difficult or impossible to recreate in real life. For the usability experiments, indoor and outdoor scenarios have been employed where the user position and relation to the virtual biometric scanner have been assessed. Initial tests and reactions allowed for a rapid evolution of the virtual prototypes in order to identify a suitable ergonomic and appealable biometric device that offers the highest usability score from the test group.

Data arriving from the Perception Neuron motion capture suit have been processed in real time using the Axis Neuron Pro application and relayed as a BVH stream (Biovision Hierarchical Data) of skeleton hierarchy and motion data to the simulation using the Unreal plugin of the Axis application. The motion to photon latency measured in the full pipeline is 27ms resulting in an adequate dynamic response of the virtual reality system while decreasing the risk of simulator sickness for the participants of the usability study.

Figure 4. Experimental setup and sensor fusion results. Test-person in front of VR station wearing Oculus Rift headset with Neuron Perception suit.

Figure 4 shows the experimental setup in the post calibration stage.

III. TESTING PROCEDURE AND RESULTS

A group of 37 people has been enrolled in the experiments. The experiments were detailed and an informed consent was obtained from all participants. The age interval is intentionally reduced and spans from 20 to 26 years. For this particular testing, the age constraint has been put in place to avoid potential false results due to different understanding and acceptance of cutting edge technology at different stages in life. The age group will be widened to be statistically relevant in future experiments after determining optimum positions and hand placement from users accustomed with the technology. All users have had a previous encounter with the same variant of a biometric vein scanner and have used the virtual reality device used in the experiments. In order to minimize external influences on the perception of the virtual system – nausea or dizziness associated with some applications of VR systems, excessive arm fatigue or altered proprioception due to sensory mismatch- several rules have been devised:

- Each user is presented with only 6 different virtual vein scanners starting from the known one. The goal is to avoid arm fatigue due to the position of the hand in the virtual scanner, a condition very similar to the "gorilla arm syndrome" exhibited by users of vertical touch screens [17].
- Movement is performed on a 1 to 1 scale and there is no vection and therefore no vestibular mismatch [18]. The user is free to roam the play area and the edges of the virtual space are marked with a subtle but easy to understand virtual grid that appears when the user is touching the borders of the play space.
- For each user, the Intra-Pupillary Distance (IPD) is measured and the height of the individual is also entered in the simulation thus preventing eye fatigue and disorientation.
- The virtual wall of the simulation is complemented by a real separator shifted 40cm outside the experiment area to increase immersion and in the same time to avoid users bumping into real walls since the virtual grid acts as an early alert system.
- There are no movable parts in the simulations or objects that might entice the user to lean on or touch, in part to avoid sensory disconnections and to prevent potential injuries.
- Generic, low feature avatars are used for the virtual bodies of the users involved in the usability experiments – setup does not elicit additional behavioral impulses [18].

For each individual user, a configuration file has been created based on their biometric data (height, IPD, vision correction parameters). In addition, every participant in the test received a 10-minute accommodation period in the testing area using the Oculus Rift headset and the Perception Neuron suit- with no biometric hardware setups shown at this stage.

Three sets of experiments have been performed using the virtual reality setup.

For experiment 1, each virtual scanner has a working area that has not been previously disclosed to the participants. Using a modified variant of the tests performed in [20], the users were asked to scan their vein patterns on a "contactless" device. The number of tries has been recorded as well as the distance of the user's hand to the biometric scanner. In addition, the ability of a user to quickly find the optimum position has been recorded as the total time between the start of the simulation and the successful scan.

Experiment 2 has been necessitated by current research of the authors in orientation and position invariant scanning algorithms. Calibration of the algorithms for hard angles (users inserting their hands in the scanning area at angles above 15°) is difficult to achieve in part due to the occlusion of veins when the hand is tilted too much. Experiments have determined that the overwhelming majority of users are below these limits and several steps can be introduced in the creation of biometric scanners to visually guide the user's hand placement.

For the last experiment, in order to verify the perceived accuracy and immersion of the experimental setup, a biometric system using a physical support handle for the hand has been modeled in the CAD software used previously. The part of the system that the user interacts with has also been physically created in Polylactic Acid (PLA) with the use of a general purpose Ultimaker 3D printer - employing the Cura software package for toolpath generation. The printed handle and support have been placed in a precise manner in the experimental area in order to match the position of the virtual handle module. This allows a level of interaction more common to an AR (Augmented Reality) setup and reveals both physical and behavioral user information.

Table 1 shows the results for the first virtual scanner-resembling the real device previously presented to the test participants.

TABLE I. USABILITY RESULTS FOR SCANNER 1

Scanner 1	**Contactless scanner usability**		
	Parameters	***Number***	***Obs.***
Exp. 1	Number of succesful first tries	31	
	Total number of tries (all users)	44	5 double tries and one triple attempt
	Average distance of hovering hand to scanner	12cm	86 % of test-users in optimum range of 10-15cm
	Average time from simulation start to successful scan	9.2 s	37 people sample size
	Lower back angle compensation for scanner height	>11° for 15% of users	Consistent with height
Exp. 2	Average angle of attack for vertical axis (roll on horizontal axis)	6°	96% of users between -15°…+15°
	Average angle of attack for horizontal axis (yaw on vertical axis)	4°	90% users between -10°…+8°
	Average angle of attack for horizontal axis (pitch on horizontal axis)	11°	68% users between -10°…+9°
	Percentage of clenched fist vs. open hand	94%	Previously instructed to

Scanner 1	**Contactless scanner usability**		
	Parameters	***Number***	***Obs.***
			use clenched fist posture
Exp. 3	Number of succesful first tries (reaching and touching real handle)	35	2 users required multiple tries- eye conditions
	Willingness to retouch – number of users	32	5 users expressed anxiety over retouching sensor 1 -either due to different feel of the texture or slight miscalibration of the visual cues. The general consensus was “lack of realism”

Complete experimental results have been gathered for all six virtual biometric scanners and the designs have been updated to take into account the usability impact assessed in the tests. In order to aim for a standardization proposal for a modular vein pattern biometric scanner, usability and ergonomics data gathered in this research will allow an academic device to gain commercial attributes difficult to quantify in a real-life experiment.

IV. CONCLUSIONS

As part of an ongoing research into the involvement of virtual reality in biometrics, this paper has attempted to depict the general hardware and software implementation of a virtual reality usability study concerning vein pattern recognition systems. Using the combination of a precise position acquisition from a virtual reality setup with the full body pose assessment of an inertial motion capture system, a complete real time user tracking system has been implemented.

The general workflow of the communication between these heterogenous systems has also been presented in the experimental setup description.

The participants in the experiments have been virtually placed in a false environment with various designs of hand vein biometric systems present in the simulation. Starting from a known, real biometric scanner, users have been asked to place their hands above or below 5 proposed scanner designs.

Several pieces of information have been successfully extracted from the experiments that add in the design of real-life biometric scanners. The paper has presented results concerning height variance and comfort rating for different scanner position and geometry. In addition, a battery of tests dealing with angle of attack measurement for unconstrained hand position has led directly to a simplification of algorithms for an orientation invariant hand vein biometric scanner. These results are relevant in both pure biometric studies and real security applications.

In order to cement the presence of virtual reality in the world of biometrics, a new experiment is underway where users are instructed to enroll in a multimodal biometric setup using five technologies (retina scan, iris recognition, finger vein, voice and fingerprints). A real setup with access to these scanning methods would be extremely difficult to construct.

By using virtual reality, small changes in the user position and behavior, coupled with the willingness to provide the biometric parameter (retinal scans perceived as intrusive and dangerous, face scanners easy to comply or fingerprint scanners -simple but carrying a “crime stigma”) offer valuable data regarding user perception of different scanning technologies.

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REFERENCES

[1] A. K. Jain, A. Ross, S. Prabhakar, “An Introduction to Biometric Recognition”, Invited paper in IEEE Transactions on circuits and systems for video technology, Vol. 14, No. 1. 2004.

[2] C. Wilson, “Vein pattern recognition: a privacy-enhancing biometric”, Taylor & Francis, ISBN 978-1-4398-2137-4I, 2010.

[3] Fujitsu Develops Technology for World's First Contactless Palm Vein Pattern Biometric Authentication System , Fujitsu Laboratories Limited, Tokyo Japan Available from http://www.fujitsu.com/global/news/pr/archives/month/2003/20030331-05.html, 2014.09.02

[4] Introducing Hitachi Finger Vein Authentication (2005). Hitachi Corporation Japan. Available from http://www.hitachi.co.jp/Prod/comp/fingervein/global, 2015.12.13

[5] S. Crisan, I. G. Tarnovan, T. E. Crisan, “A Low Cost Vein Detection System Using Near Infrared Radiation”, IEEE SAS, San Diego, USA, 2007

[6] S. Crisan, I. G. Tarnovan, T. E. Crisan, “Radiation optimization and image processing algorithms in the identification of hand vein patterns”, Computer Standards and Interfaces, Volume 32, Issue 3, pp 130, Elsevier, 2010

[7] S. Crisan, “Researches concerning the development of biometric applications using infrared radiation”, PhD Thesis, Technical University of Cluj-Napoca, 2008

[8] S. Crisan, I. G. Tarnovan, B. Tebrean, T. E Crisan, “Corellation of near and far infrared vein recognition for unified processing and simulation”, XIX IMEKO World Congress Fundamental and Applied Metrology, Lisbon, Portugal. 2009

[9] S. Crisan, I. G. Tarnovan, B. Tebrean, T. E. Crisan, “Hand Vein Biometric Authentication in Optical Multi-touch Systems” In International Conference on Advancements of Medicine and Health Care through Technology (pp. 124-127). Springer Berlin Heidelberg, 2011

[10] S. Crisan, B. Tebrean, S. Emerich, “Optimized Vein Pattern Recognition for Biometric Applications, a Modern Approach” 14th IMEKO TC10 Workshop Technical Diagnostics New Perspectives in Measurements, Tools and Techniques for

system's reliability, maintainability and safety Milan, Italy, June 27-28, 2016

[11] S. Crisan "A Novel Perspective on Hand Vein Patterns for Biometric Recognition. Problems, Challenges and Implementations". Chapter in Biometric Security and Privacy. Opportunities & Challenges in The Big Data Era. Signal Processing for Security Technologies series. Jiang, R., Al-Madeed, S., Bouridane, A., Crookes, D., Beghdadi, A. (Eds.) 2017

[12] S. M. Lavalle, Virtual Reality, Cambridge University Press, 2017

[13] P. R. Desai, P. N. Desai, K. D. Ajmera, K. Mehta, "A review paper on oculus rift-a virtual reality headset". arXiv preprint arXiv:1408.1173, 2014

[14] D. Sharma, "A Review Paper On Virtual Reality Oculus Rift And Augment Reality", International Journal of Current Research, Vol. 8, Issue 9, pp. 37941-37945, 2016

[15] Oculus 3-Sensor 360° Experimental Setup, Upload VR, Available from https://uploadvr.com/oculus-guides-show-smaller-multi-sensor-tracked-spaces-htc-vive/, 2017.02.04

[16] W. Mason "Perception Neuron Review: In-Depth With The $1,500 Motion Capture Suit", Available from http://uploadvr.com/perception-neuron-review/, 2015.11.04

[17] S. Boring, J. Marko , A. Butz. "Scroll, tilt or move it: using mobile phones to continuously control pointers on large public displays." Proceedings of the 21st Annual Conference of the Australian Computer-Human Interaction Special Interest Group: Design: Open 24/7. ACM, 2009.

[18] A. I. Mallinson, "Visual Vestibular Mismatch." PhD diss., Université Henri Poincaré, 2011.

[19] J. Blascovich, J. Bailenson, "Infinite reality: Avatars, eternal life, new worlds, and the dawn of the virtual revolution", William Morrow & Co, 2011

[20] M. Jokisch, T. Bartoschek, A. Schwering, "Usability testing of the interaction of novices with a multi-touch-table in semi public space", Institute for Geoinformatics, University of Münster, 2010