Use of Creative Materials for Fingerprint Spoofs

Ondřej Kanich, Martin Drahanský
Faculty of Information Technology
Brno University of Technology
Brno, Czech Republic

Martin Mézl
Faculty of Electrical Engineering and Communication
Brno University of Technology
Brno, Czech Republic

***Abstract*—The aim of this article is to describe the usage of creative materials for fingerprint spoofs. The majority of these materials are used in some kind of modeling (hence creative materials). In total 21 materials were tested. PCB mold was created from fingerprints taken by various semi-cooperative methods. Using this mold the first set of materials was tested. From these materials the best ones were chosen to be the second stage. Spoofs from the second stage were acquired by several sensors and evaluated by NFIQ and COTS product software. The most promising materials which were tested are latex, Siligum and wax sheet.**

Keywords— fingerprint, spoofing, synthetic fingerprint, creative materials

I. Introduction

With the boom of personal devices secured by fingerprint technology there is more attention focused on the ways of bypassing them. The motivation for doing so may be lawful or unlawful. Whenever new smartphone flagship is released it usually raises attention if the security of the device can be breached or not. There have also been some cases where the law enforcement agencies want to get into the smartphone of a terrorist [1]. In the case of a stolen device, it is likely that thief who stole such a device also wants to unlock it. All these people desire to break into the device.

There are various ways how to breach the security of the smartphone. This article focuses on using fake fingerprint to overcome a fingerprint sensor. Fig. 1 shows possible ways of breaking into a fingerprint protected device. There is cooperative branch which presumes that the mold can be done directly with the cooperation of the person which is impersonated. That is usually not the case and there are four other possibilities left. Either the latent fingerprint can be reactivated on the device which is possible for some fingerprint sensor types or a cadaver finger or cut finger can be used. All these options presume some cooperation or very specific actions of the original user. Without this cooperation or specific actions from the original user, the only remaining action presumes that the latent fingerprint can be obtained. Then image quality can be enhanced by automatic or manual reconstruction the latent fingerprint or directly make the fingerprint spoof from a digitized latent fingerprint. [2, 3, 4, 5]

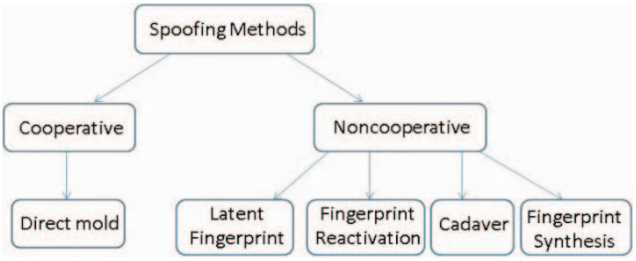

Fig. 1. Overview of various spoofing methods.

II. Preparation Phase for Spoof Production

This chapter describes methods used for preparation and production of a mold. It also present methods used to evaluate and making of a spoof. Materials used for these spoofs are listed and finally description and all sensors used in evaluation are shown with their description.

A. Production of Molds

As the first step of the production of the mold, latent fingerprints need to be acquired. A combination of cooperative and non-cooperative methods was used – volunteers cooperatively made fingerprint scans but the rest of the production was without their cooperation. Fingerprints of five volunteers were acquired using a standard police fingerprint card, a capacitive touch sensor UPEK EikonTouch, a capacitive sweep sensor UPEK Eikon II and an optical touch sensor SecuGen Hamster III. The scans were done repetitively with an evaluation of the fingerprint quality.

Afterwards, the process continued without cooperation of the original volunteers. The fingerprints acquired by fingerprint card were scanned and digitalized. The digital fingerprint images from all methods of scanning were processed using histogram equalization and thresholding to get a binary representation of the fingerprint. In the process, some manual image enhancements (mainly restoration of the papillary lines) were made. In the second step, the binary representations of all fingerprints were inverted and converted to a PCB (Printed Circuit Board) drawing file. The molds of all templates were made using standard PCB with HAL led free finish and

separation with CH14 separator (Dawex Chemicals). [3, 5, 6, 7]

An additional mold was made by the same method from synthetic fingerprints in the master fingerprint phase [8]. That is because of poor quality of some real fingerprints. In this phase the generated fingerprint is perfect as you can see on the right side of Fig. 2. On the left side you can see a real fingerprint. The difference between these two is the reason why we made fingerprint spoofs from synthetic fingerprints. The validation then will not be influenced by errors made when capturing the fingerprint. That means that final evaluation should be more accurate. [6, 8]

Fig. 2. Difference between real fingerprint and synthetic one.

B. Making of Spoofs

Altogether 21 materials (Fimo Standard, Fimo Air, Kera, Hobby Mass, Magic Putty, WePAM, Mamut glue, Acrylic sealant, Herkules glue, Oyumare, Play-doh, Vegetable play-doh, Premo, Tropicalgin, Glass colors, Cernit, Gel wax, Kato, Siligum, Latex, Wax sheets) were tested for production of spoofs. Chosen materials are predominantly used in art hence the name creative materials. Materials were used as they were without any special additives or special separators. There were pushed into the mold and if needed waited till hardened. The making of spoofs was done in two stages. In the first stage spoofs were prepared from all materials. After that they were evaluated visually and by scanning the spoof with various scanners. After this stage, seven materials (Glass colors, Cernit, Gel wax, Kato, Siligum, Latex, Wax sheets) were chosen as feasible for the more thorough evaluations and experiments. Both synthetic and real molds were used on these spoofs and fingerprint image quality was evaluated.

C. Sensors Used for Evaluation

For spoofs acquisition several sensors were used: contactless optical 3D sensor TBS 3D Enroll System, pressure touch sensor BMF EZF 650, optical touch sensor Secugen Hamster III, Dino-Lite digital microscope and optical touch sensor Lumidigm Venus with multispectral liveness detection. It was added to whether this type of liveness detection can be bypassed by some of the spoofs. [3, 8, 9]

III. Spoofs Evaluation

In this chapter detailed description of materials and their results will be shown. Images of the materials on the mold and some example images that were taken are also shown. Materials chosen to the second stage of experiments with better evaluation, have in addition table with results and images from all fingerprint sensors.

Fimo Standard is a polymer clay which is used to make jewelry and accessories. It is easily malleable and can be hardened by baking in oven. After that the clay is hard and keeps its shape so it can be drilled, sliced etc. Production of fingerprint spoofs was without the baking part. The Fimo Standard spoofs were very shapeable. They were also losing papillary lines shape quickly, especially on the pressure sensor. Below on Fig. 3 images of this material can be seen

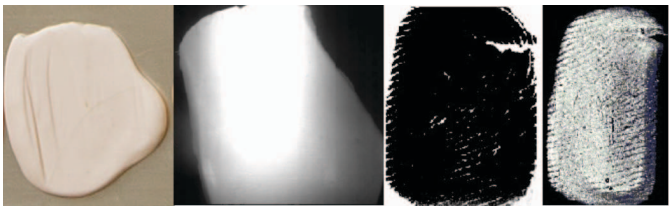

Fig. 3. Fimo Standard spoofs images (photo, TBS, Secugen, BMF).

Fimo Air is special type of Fimo clay which can be hardened by leaving it exposed to air, which was done. The fakes were parched and hard so that they could not be used on touch sensors.

Kera is a ceramic material which, similarly to the Fimo air, can be air-hardened. Fingerprint spoofs were hardened which influenced their properties. Acquiring fingerprint spoofs made of this material caused cracks in them and they were so dry that they could not be used on touch sensors. Below on Fig. 4 images of Fimo Air and Kera materials can be seen.

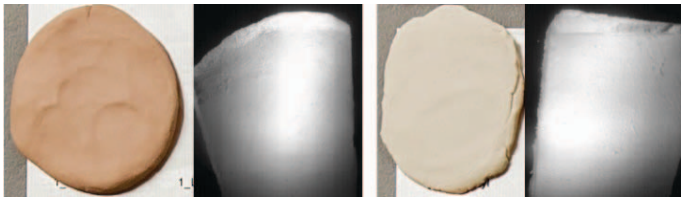

Fig. 4. Fimo Air (left) and Kera (right) spoofs images (photo, TBS).

Hobby Mass is a modelling material with a polymer base. It is designed for art creation and it is similar to Fimo. It can be hardened by baking in oven or in boiling water. Fingerprint spoofs were not hardened. That resulted in malleable spoofs that are destroyed very quickly. They are giving poor results

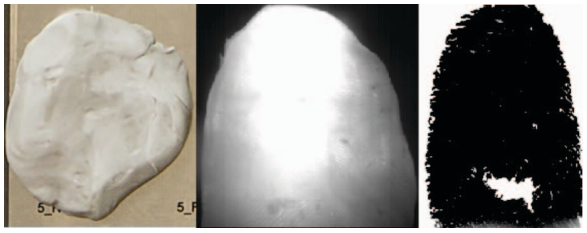

Fig. 5. Hobby Mass spoofs images (photo, TBS, Secugen).

with the pressure sensor because the pressure cannot be applied. Below on Fig. 5 images of this material can be seen.

Magic Putty is a material based on the silicone polymers with viscoelastic properties. It is a type of non-Newtonian fluid. This material takes shape of a fingerprint really quickly but can be used only once, and, after that it takes the shape of the sensor which was used.

WePAM is another polymer clay. It is solid, really hard to knead and it hardens itself in the air. Steady pressure should have been applied when WePAM hardens itself, because there is only part of the original fingerprint on the spoof. Also, it is

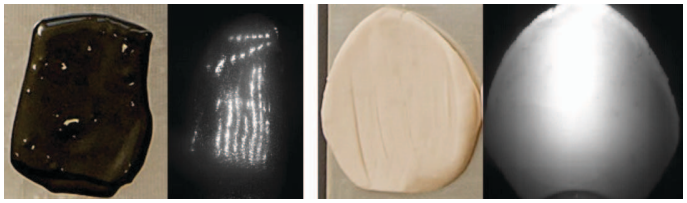

Fig. 6. Magic Putty (left) and WePAM spoofs images (photo, TBS).

possible that the material did not harden correctly. The result is hard and cannot be used on touch sensors. Below on Fig. 6 images of this material can be seen.

Mamut glue is a special modification of silyl modified polymer. It makes an elastic but very firm joint which is watertight and can be used on a wide range of materials. *Acrylic sealant* is used for filling gaps between window frame, door frame and other cracks in plaster, etc. *Herkules glue* has a polyvinyl acetate base. It is intended to be used on absorbent materials like paper, wood, leather, etc. Mamut glue and acrylic sealant are almost impossible to get out of the mold. The spoof

Fig. 7. Mamut Glue, Acrylic Sealant, Herkules Glue spoofs images (photos).

tears apart and stretches out so the spoof cannot be used. Herkules glue, even when heated, cannot be taken from the mold. Below on Fig. 7 images of these materials can be seen.

Oyumare is a silicone based reusable modelling compound.

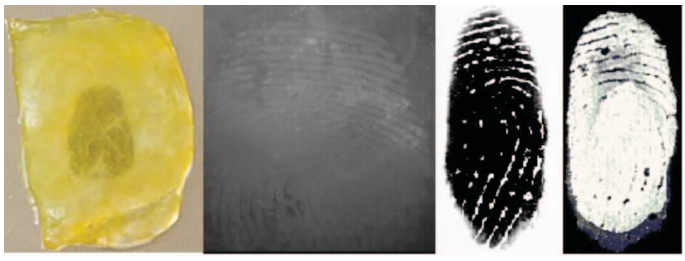

Fig. 8. Oyumare spoofs images (photo, TBS, Secugen, BMF).

When heated in boiling water it gets soft. After cooling, it hardens back into rubbery flexible plastic. It keeps the shape of the fingerprint. When acquiring the fingerprint image really heavy pressure needs to be applied. It is possible to make better spoof by using a thin layer of Oyumare. Below on Fig. 8 images of this material can be seen.

Play-Doh is a modelling clay designed mainly for children. It is soft and malleable and it cannot be hardened. Although there are several types of play-doh that can harden in the air when they are not used for a long period. When using spoofs from this material one has to pay attention to use gentle

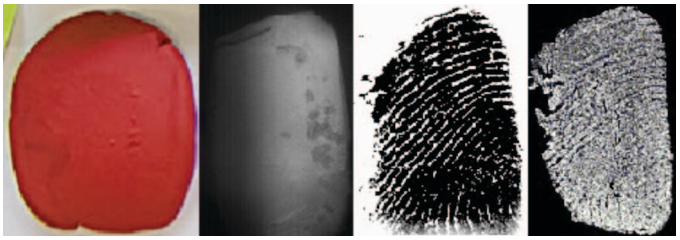

Fig. 9. Play-Doh spoofs images (photo, TBS, Secugen, BMF).

pressure otherwise the spoof can be damaged. Below on Fig. 9 images of this material can be seen.

Vegetable Play-Doh is a variation of the previous material. The difference is in usage of a vegetable substance as ingredient. This should lead to a bigger volume and more shapeable result. The difference in usage is tremendous. This material needs excessive pressure to create fingerprint image on the sensor. It took several tries to create one. Similarly, after

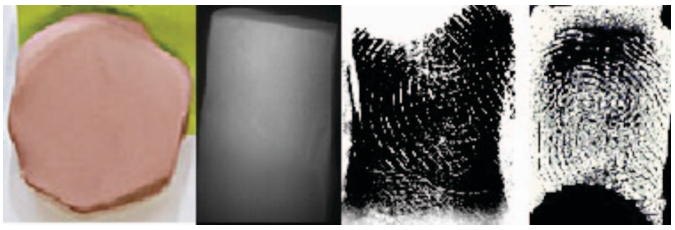

Fig. 10. Vegetable Play-Doh spoofs images (photo, TBS, Secugen, BMF).

usage it degrades and slowly loses its shape. Below on Fig. 10 images of this material can be seen.

Premo is similar to Fimo with a few small differences (e.g. it is easier to blend colors together). Gentle pressure to make a fingerprint spoof is needed. It is easy to create cracks in material when applying on sensors as you can see in Fig. 11.

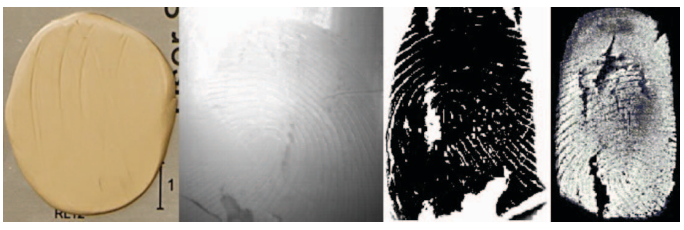

Fig. 11. Premo spoofs images (photo, TBS, Secugen, BMF).

Tropicalgin is an impression-making material used in dentistry. The basis of this material is sodium alginate that can be obtained from the cells of brown algae. It is distributed as a powder which can be mixed with water. Water starts changes that are indicated by different colors. Red color indicates mixing phase, orange working phase and yellow phase when mixture starts to solidify. Alginate basis slowly evaporates and spoofs becomes too parched to be used. Spoofs shown below were stored in a plastic bag with water to prevent evaporation. Below on Fig. 12 images of this material can be seen.

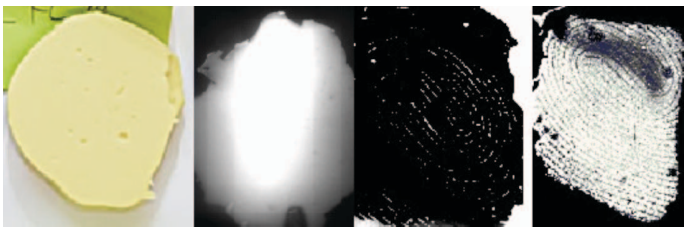

Fig. 12. Tropicalgin spoofs images (photo, TBS, Secugen, BMF).

A. Second Stage Spoofs Evaluation

In this part the most promising materials were used to make second stage spoofs. There were 5 or more spoofs from these materials made using both real and synthetic mold and they were tested on more sensors and statistics of these spoofs were made. Each material was tested on all sensors mentioned in Chapter Sensor Used for Evaluation.

Images of spoofs acquired by the Secugen and BMF sensors were evaluated by several metrics. NIST standard for quality assessment - NFIQ, commercial off the shelf product for fingerprint recognition (referenced as COTS product further in the text) software quality assessment and score against the original mold and original fingerprint. NBIS (respectively NFIQ) version 5.0.0 was used [10]. The difference between these two is that some molds were made using the same finger but a different method of fingerprint acquisition. Some fakes have a higher score on a mold made from a higher quality image of the real fingerprint than on their respective mold. The fingerprint score was determined in 3 different settings of the COTS product software. First were the default settings that means each fingerprint image under the quality score of 40 was ignored. To get more results, the second setting was half quality: that means each fingerprint under the quality of 20 was ignored. The last scenario was without quality restrictions: that means each fingerprint image was used. To create more relevant values, the percentage of original mold quality achieved by spoof is shown. Each table includes the best value and median value. Maximal values are shown in the best values row, except for NIST quality, where 1 is the best and 5 is the worst, thus minimal value is shown. Second row consist of median value, except for COTS product quality percentage where mean value is used instead. To put COTS product score into perspective, there is formula which transforms score to false acceptance rate (FAR). FAR is the probability of a situation when a non-matching fingerprint is falsely matched. [11]

$$score = -12 \cdot \log_{10}(FAR) \quad (1)$$

That means that score 48 is 0.01% FAR, 60 is 0.001% FAR and finally 96 is 0.000001% FAR. [11]

Glass Colors are special colors which can be used on glass, windows, mirrors, bathroom tiles, etc. The colors are applied to a plastic foil after that they can be peeled off and stuck to another similar surface. The mold can be filled with a really thin layer by pouring a small drip and spreading the color with a knife. If it is too thin, then it stretches out and can even tear apart while removing it from the mold. Spoofs can be done also by just pouring the color until it fits the mold. Heavier pressure is needed to get good results. Also, if presenting a spoof with a real finger it is better to cover the real finger with paper otherwise the real finger can be acquired through the spoof. Glass colors were one of the easiest to use, simple to made, easy to remove, present to the sensor and also persistent.

Final evaluation of the spoofs shows bad results in median in NIST quality but decent results in COTS product score. Also, descending trend of median score results shows that there were spoofs which have low quality and poor results. The best spoof has 78% quality of its original, based on COTS product quality measure. Below on Table 1 and Fig. 13 results of this material can be seen.

TABLE I. STATISTICS OF THE GLASS COLOR SPOOFS.

	NIST Quality	**COTS product Quality [%] from Mold**	**COTS product Score**					
			Full Quality		***Half Quality***		***Zero Quality***	
			Mold	***Finger***	***Mold***	***Finger***	***Mold***	***Finger***
Best	2	78.00%	117	117	117	117	117	117
Median	5	44.80%	64	74	53	55	41	42

Fig. 13. Glass color spoofs images (Dinolite, TBS, original fingerprint, Secugen, BMF).

TABLE II. STATISTICS OF THE CERNIT SPOOFS.

	NIST Quality	COTS product Quality [%] from Mold	COTS product Score					
			Full Quality		*Half Quality*		*Zero Quality*	
			Mold	*Finger*	*Mold*	*Finger*	*Mold*	*Finger*
Best	2	63.64%	113	113	113	113	100	100
Median	5	39.72%	80	80	39	39	31	31

Fig. 14. Cernit spoofs images (Dinolite, TBS, original fingerprint, Secugen, Lumidigm).

Cernit is a polymeric clay and is considered one of the strongest ones. It can be hardened by baking in an oven. Fingerprint spoofs were made without the hardening phase. The results are more persistent than the other polymeric clays but still fade after several usages. If used only as a thin layer, then there is a problem with sticking to the mold. Because of that it cannot be removed from the mold without great damage to the spoof. It is notable that made spoofs have the second best results in Lumidigm sensor.

Final spoofs belong among the worse. Only 39% median of quality and descending trend of scores shows that low quality spoofs also have bad results. Looking at the best results, 64% quality of real fingerprint and 113 score in COTS product are still pretty decent results. Below on Table 2 and Fig. 14 results of this material can be seen.

Gel wax itself is a combination of polymer resin and mineral oil. When heated in boiling water the gel gets to a liquid state. After cooling down to room temperature it is solid (jelly) again. There is a risk of damage to the spoof caused by air bubbles. Because of this jellylike consistence it is hard to work with the spoofs on the touch based sensors. Despite that it shows some results when used on the Lumidigm sensor.

Results for this material show the best NIST quality in terms of minimal value and median value. That is a little bit strange because the best NIST quality image is full of air bubbles. 30% of median quality of the original fingerprint and increasing score shows that there were more poor spoofs made. A maximum score of 8 when using standard settings of the COTS software is horrible. Overall the results in COTS product are the worst of all spoofs in this paper. Which is probably caused by bad results on touch based sensors. Below on Table 3 and Fig. 15 results of this material can be seen.

Kato polyclay is considered to be the strongest polymeric clay. It can be hardened by baking in the oven. When making spoofs, Kato was not hardened. It can be used as Cernit or Fimo. Thin layers are irremovable from mold. Also if pushed hard into the mold, removal can be difficult. Note that BMF image is from different finger than the others.

Kato is the second best in minimal NIST quality. Otherwise all the results are average when compared to other materials.

TABLE III. STATISTICS OF THE GEL WAX CANDLES SPOOFS.

	NIST Quality	COTS product Quality [%] from Mold	COTS product Score					
			Full Quality		*Half Quality*		*Zero Quality*	
			Mold	*Finger*	*Mold*	*Finger*	*Mold*	*Finger*
Best	1	63.10%	4	8	20	20	25	27
Median	2	29.83%	4	6.5	10	16	12	15

Fig. 15. Gel wax spoofs images (Dinolite, TBS, original fingerprint, Secugen, Lumidigm).

TABLE IV. STATISTICS OF THE KATO SPOOFS.

	NIST Quality	COTS product Quality [%] from Mold	COTS product Score					
			Full Quality		*Half Quality*		*Zero Quality*	
			Mold	*Finger*	*Mold*	*Finger*	*Mold*	*Finger*
Best	1	70.00%	129	129	129	129	129	129
Median	3	40.71%	81	81	46.5	48	42	46.5

Fig. 16. Kato spoofs images (Dinolite, TBS, original fingerprint, Secugen, BMF, Lumidigm).

Interesting is the descending median score, which, once again, means that the poor quality spoofs where also ones with the poor results. Below on Table 4 and Fig. 16 results of this material can be seen.

Latex is a white fluid which can be found inside of some plants. It is a base for natural rubber, tires, etc. When making spoofs, the biggest challenge is to make an equally thick layer of latex. A very thin layer of latex cannot be removed from the mold. Sometimes a real finger is acquired through the latex spoof and in that case it is better to cover your finger with paper. These spoofs show the best results on Lumidigm sensor.

By NIST quality latex spoofs are one of the worst. However, they are the best when comparing by COTS product quality and score in the standard settings. This implies that the best overall made spoof is from latex (98% from the original fingerprint quality). Below on Table 5 and Fig. 17 results of this material can be seen.

Siligum is two components (blue and white) silicon modelling paste. When you mix both components together in 1 to 1 ratio, light blue mixture is made. In this state it should be pushed into the mold and after around 5 to 15 minutes it makes solid but supple fake. From experience when pushing the mixture to the mold the pressure should be even and greater force can be applied. It is one of the materials which is the easiest to work with. If the spoof is larger than the sensing area a really great pressure is needed to bend the edges of the spoof and acquire it. Using pressure is not a problem because the spoof keeps its shape.

The median values are the second best which supports the idea of the easiest work with this material. It is the third in COTS product maximal score in the full quality restriction. In COTS product quality measurement it is only average. Below on Table 6 and Fig. 18 results of this material can be seen.

Different types of waxes are synthesized by some plants and animals. For making of fingerprint spoofs a *wax sheet* was used. These sheets are originally designed for dentists. They can be heated until the wax gets soft and can be pushed to the mold. Pushing into the mold has to be done carefully. The wax cools really quickly, but if it is heated and pushed too much then the result is bad. Temperature of the wax and pressure used should be balanced. The made spoof fades away after several uses. Note that spoofs made of wax can be acquired by a pressure sensor. Images from BMF were accidentally deleted – that is why they are not included here.

TABLE V. STATISTICS OF THE LATEX SPOOFS.

	NIST Quality	COTS product Quality [%] from Mold	COTS product Score					
			Full Quality		*Half Quality*		*Zero Quality*	
			Mold	*Finger*	*Mold*	*Finger*	*Mold*	*Finger*
Best	2	97.92%	455	455	455	455	455	455
Median	5	41.16%	240.5	247.5	101	101	37	49

Fig. 17. Latex spoofs images (Dinolite, TBS, original fingerprint, Secugen, BMF Lumidigm).

TABLE VI. STATISTICS OF THE SILIGUM SPOOFS.

	NIST Quality	COTS product Quality [%] from Mold	COTS product Score					
			Full Quality		*Half Quality*		*Zero Quality*	
			Mold	*Finger*	*Mold*	*Finger*	*Mold*	*Finger*
Best	2	76.00%	239	239	239	239	239	239
Median	3	41.73%	174	174	49	49	47	47

Fig. 18. Siligum spoofs images (Dinolite, TBS, original fingerprint, Secugen, BMF).

Results of the wax spoofs are one of the best. Median of COTS product percentage quality from original fingerprint is the best and the second best in maximal values. Score of the best fingerprint is also the second best from all these materials. Below on Table 7 and Fig. 19 results of this material can be seen.

IV. CONCLUSION

For the final evaluation the best spoof made of each material was chosen. These best spoofs were determined by the COTS product software score in standard (full) quality restriction. While the median values of each material show more or less how successful spoof production was, they are also influenced by the quality of the molds chosen for each spoof. The best spoofs for each material could be based on different mold. 5 of 7 materials are from the synthetic fingerprint mold. Remaining materials have the best spoofs from one specific finger. COTS product quality of the best mold made from that specific finger is 91, in the case of synthetic molds the quality is from 96 to 100. That means that the quality of the molds is comparable to each other. The best spoofs would be also chosen for real use. Their results can be seen on Table 8.

TABLE VIII. COMPARISON OF THE BEST SPOOFS FROM EACH MATERIAL.

Material	NIST quality	COTS product Quality [%]	COTS product Score
Latex	5	89.58%	455
Wax sheet	2	96.00%	360
Siligum	3	76.00%	239
Kato	3	53.49%	129
Glass colors	5	61.00%	117
Cernit	2	51.04%	100
Candle gel	2	48.31%	8

TABLE VII. STATISTICS OF THE WAX SPOOFS.

	NIST Quality	COTS product Quality [%] from Mold	COTS product Score					
			Full Quality		*Half Quality*		*Zero Quality*	
			Mold	*Finger*	*Mold*	*Finger*	*Mold*	*Finger*
Best	2	96.00%	360	360	360	360	360	360
Median	4	49.97%	68.5	87.5	60	73	57.5	72

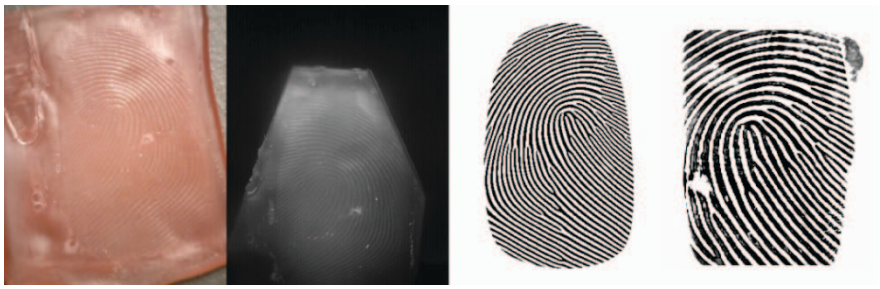

Fig. 19. Wax spoofs images (Dinolite, TBS, original fingerprint, Secugen).

Final results show the three best materials. Wax for the best quality and score ratio. Latex as the best material for spoofing with the highest score, and finally the Siligum which has pretty decent results and was one of the easiest to use. On the other side of the table is the candle gel whose results on touch based sensors were not promising and that was confirmed.

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