Supporting information for

Versatile and Validated Optical Authentication System based on Physical Unclonable Functions

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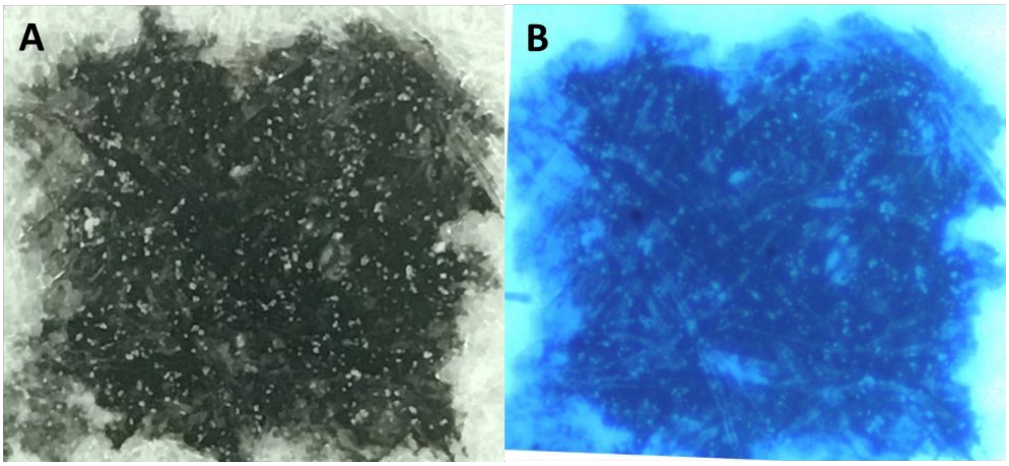

Figure S1. Luminescent PUF-tag sprayed onto a QR code printed on Lyreco multi-purpose white labels: $Y_3(Al,Ga)_5O_{12}:Tb^{3+}$ phosphor. A) Image of the scattering of QMPK65/F-C1 ($Y_3(Al,Ga)_5O_{12}$:Tb, 1.5-6.5 µm particle size, Phosphor Technology) taken with iPhone 7 equipped with Nurugo Micro Microscope, B) fluorescence image of the terbium luminescence taken with an Olympus IX71 microscope and 330-385 nm bandpass excitation and 420 nm longpass emission filters (filter cube U-MWU2, Olympus). The black printed square in the picture is about 0.5 × 0.5 mm in dimensions.

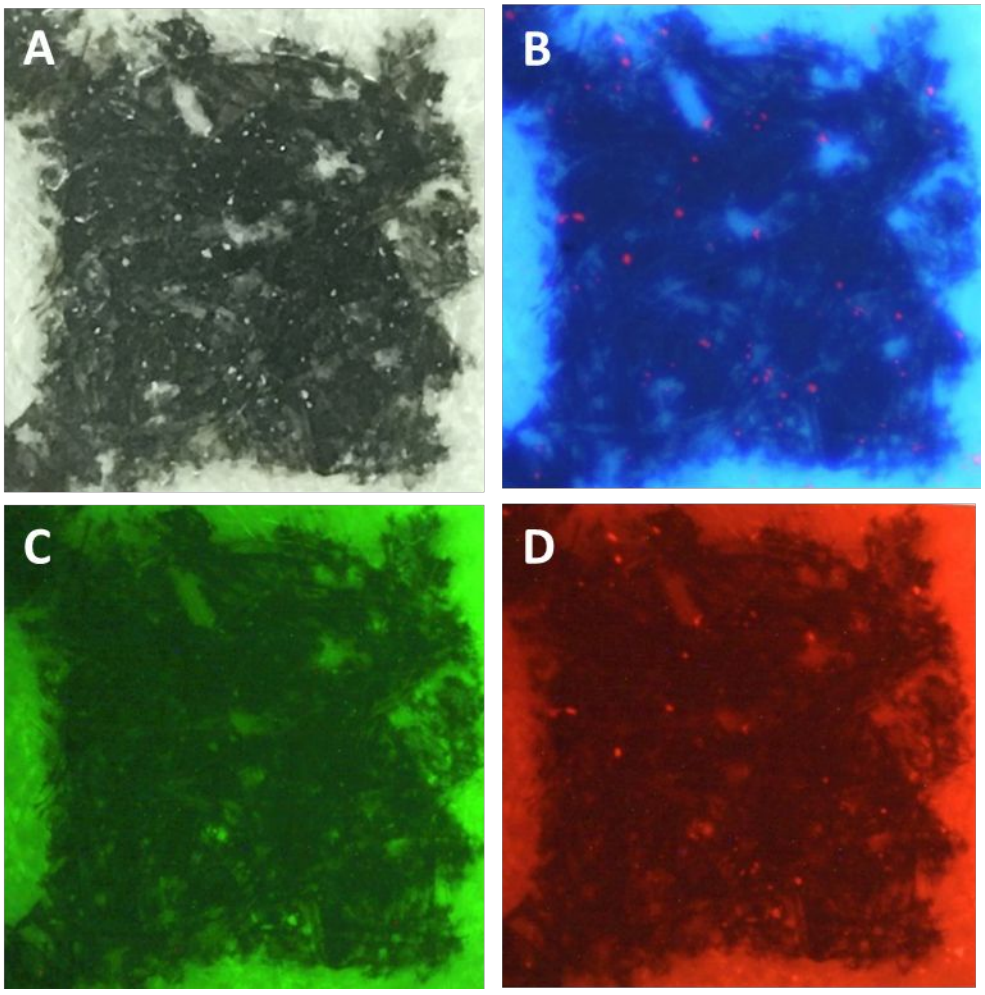

Figure S2. Luminescent PUF-tag sprayed onto a QR code printed on Lyreco multi-purpose white labels: mixture of $(Gd,La)_2O_2S:Eu^{3+}$ and $Gd_2O_2S:Tb^{3+}$ phosphors. A) Image of the scattering of a mixture of U5KL63 ($(Gd,La)_2O_2S:Eu^{3+}$, 2.3—12.6 µm particle size) and UKL65/F-R1 ($Gd_2O_2S:Tb^{3+}$, 1.9—6.8 µm particle size, Phosphor Technology) phosphors taken with iPhone 7 equipped with Nurugo Micro Microscope, B-D) fluorescence image of the europium and terbium luminescence taken with an Olympus IX71 microscope and B) 330-385 nm bandpass excitation and 420 nm longpass emission filters (filter cube U-MWU2, Olympus), C) 470-495 nm bandpass excitation and 510-550 nm bandpass emission filters (filter cube U-MNIBA3, Olympus) and D) 510-550 nm bandpass excitation and 590 nm longpass emission filters (filter cube U-MWG2, Olympus). The black printed square in the picture is about 0.5 × 0.5 mm in dimensions.

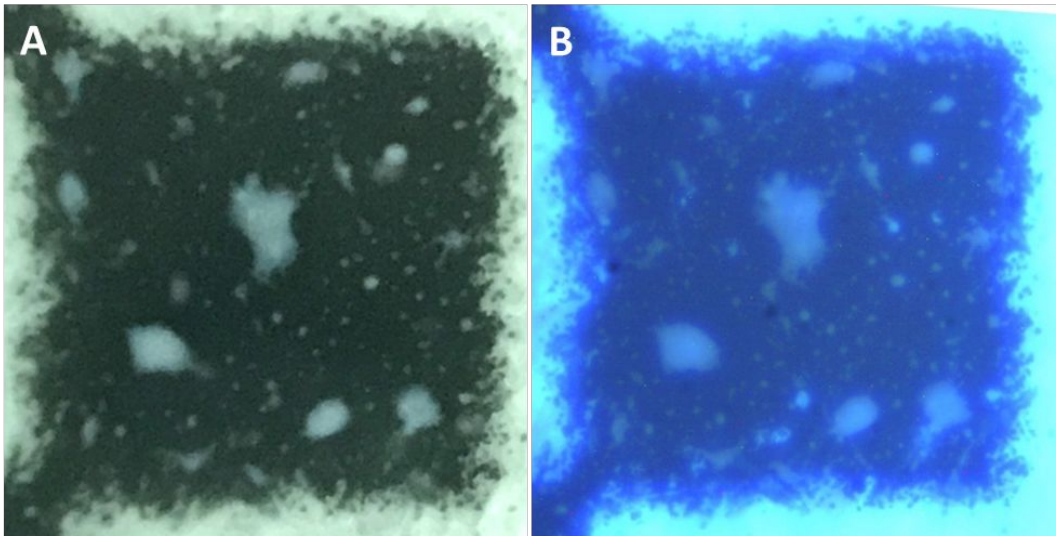

Figure S3. Luminescent PUF-tag sprayed onto a QR code printed on Lyreco multi-purpose white labels: mixture of $TbCl_3$ and ZnO. A) Image of the scattering of a mixture of $TbCl_3$ and ZnO taken with iPhone 7 equipped with Nurugo Micro Microscope, B) fluorescence image of the terbium luminescence taken with with an Olympus IX71 microscope and 330-385 nm bandpass excitation and 420 nm longpass emission filters (filter cube U-MWU2, Olympus). The black printed square in the picture is about 0.5 × 0.5 mm in dimensions.

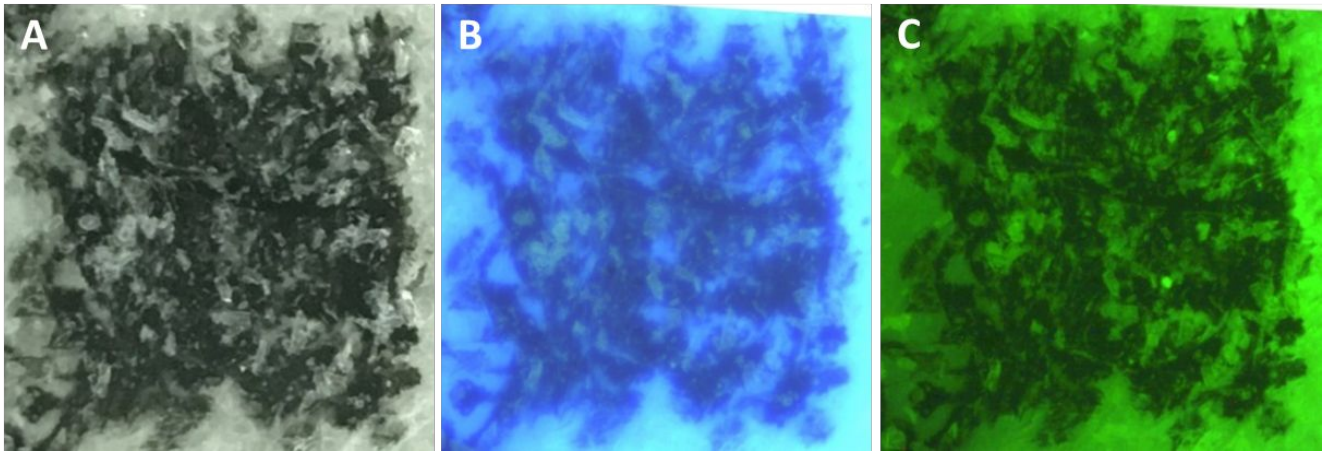

Figure S4. Luminescent PUF-tag sprayed onto a QR code printed on Lyreco multi-purpose white labels: Tb-acac. A) Image of the scattering of Tb-acac taken with iPhone 7 equipped with Nurugo Micro Microscope, B-C) fluorescence image of the terbium luminescence taken with with an Olympus IX71 microscope and B) 330-385 nm bandpass excitation and 420 nm longpass emission filters (filter cube U-MWU2, Olympus), and C) 470-495 nm bandpass excitation and 510-550 nm bandpass emission filters (filter cube U-MNIBA3, Olympus). The black printed square in the picture is about 0.5 × 0.5 mm in dimensions.

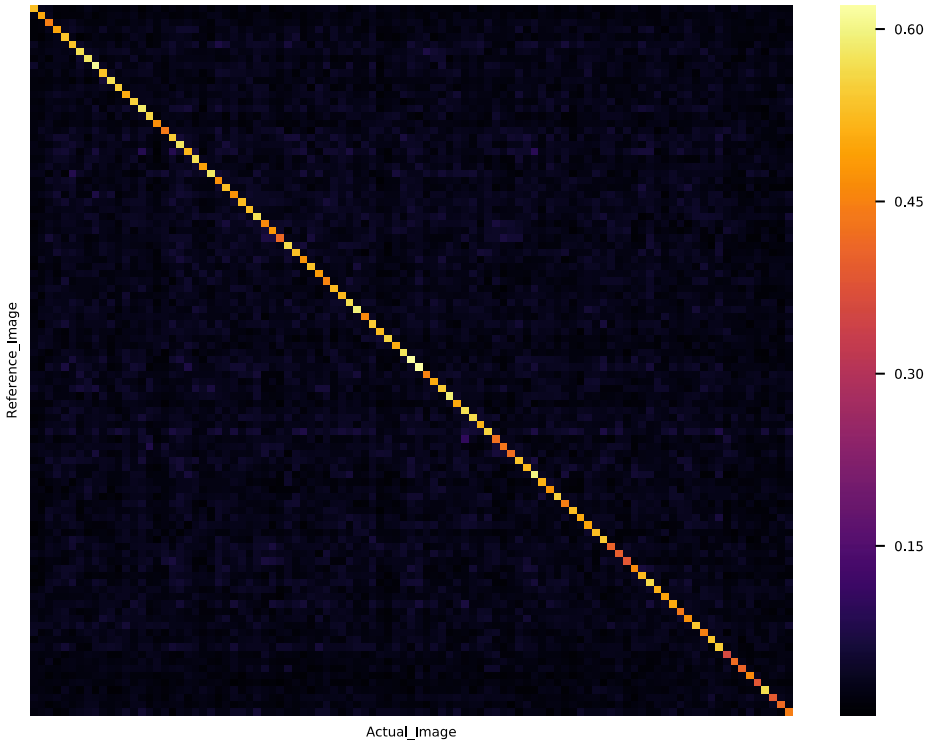

Figure S5. Match scores of 100 PUF-tags (Reference_Image) ran against reimaged pictures (Actual_image) of the same tags. The color bar shows the match scores. The PUF-tags were manufactured using spray coating on QR codes printed either by a laser printer or four different inkjet printers, and the microparticles included TiO_2, ZnO, K_2WO_4:Eu, $Y_3(Al,Ga)_5O_{12}$:Tb, $(Gd,La)_2O_2S$:Eu + Gd_2O_2S:Tb -mixture, $TbCl_3$ + ZnO -mixture, and Tb-acac. All three corners of a QR code were used as PUF-tags, giving three replicas of each microparticle – printer -combination.

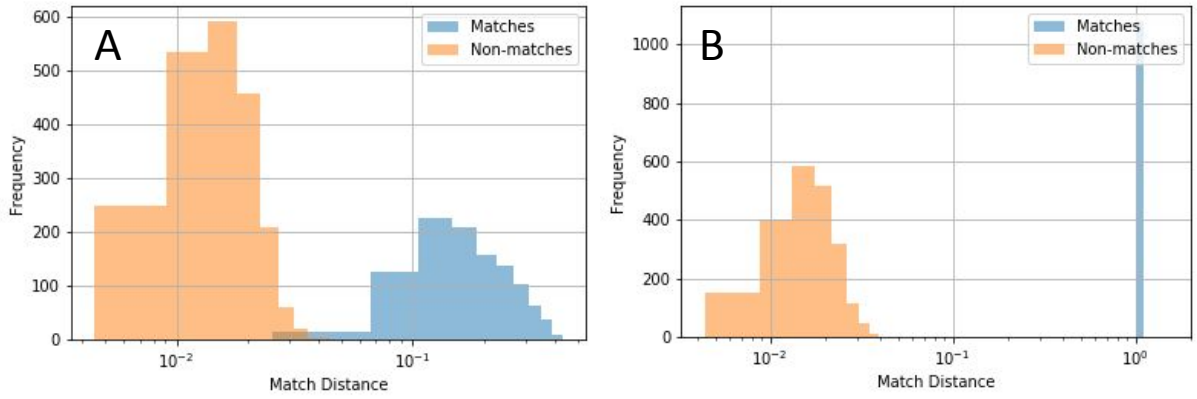

Figure S6. The separation between true (blue) and false (orange) matches on an arbitrary match score axis for validation of PUF-tag images matched against A) the reimaged pictures or B) matched against themselves.