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Portable MAXRF system development using a low power X-ray tube and a Raspberry Pi microcomputer

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1. Introduction

Macro X-ray fluorescence analysis (MAXRF) scanning is a technique that has been used for Archeometry area include investigation of historical paintings. Elementary distribution images acquired by this method can reveal hidden sub-surface layers including modifications made by the artist, provide information about the artist's creative process and his paint palette, also restorations or conservation history of painting. Research centers and universities have been developing portable XRF systems, motivated by simplicity in assembly and ease in obtaining the associated technology with this technique [1][2][3][4]. The commercial MAXRF equipment is not suitable for researchers because often need more information, beyond data collection, and the usual equipments can hardly be modified for general purposes [5][6][7][8][9]]. This work aims to develop a low-cost, portable, automated, MAXRF system using a Raspberry Pi microcomputer. This system can be remote controlled by a device connected to a Internet. In the XRF system were used a low power X-ray tube (Au anode, 40 kV, 200 µA) and an SDD type detector with PX5 digital pulse processor. There were four modules: three movement stages (module X, module Y and module Z) and an electronic module that is a control center managed by a Raspberry Pi microcomputer. A Brazilian wooden handcraft was measure with this system at Laboratório de Instrumentação Eletrônica e Técnicas Analíticas (LIETA).

2. Methodology

The MAXRF system (Fig. 1) was developed like a low-cost equipment, which makes two-dimensional mappings in cultural heritage assets. For this, the main system characteristic is the portability, since the ideal is to take measurements in-situ. The system have four modules (module X, module Y, module Z and electronic module), which fit together. The module X is responsible for the system movement in relation to the horizontal (X-axis). The module Y is responsible for the system movement in relation to vertical (Y-axis). The mapping size area is 0.86 m x 0.80 m. The module Z is responsible for XRF data acquisition. It is composed of a movement sub-module, to adjust the system focus in relation to the sample. Coupled on top, there is a data acquisition sub-module composed of the alignment system equipment in relation of the sample, the low-power X-ray tube (50 kV, 200 µA, 4 W, 1 mm collimator, Au anode), model MiniX, and the SSD detector (resolution of 1.25 eV to Fe-Kα), model XR-100SDD, with a PX5 digital pulse processor, both from Amptek. Finally, the electronic module control the entire system movement and process the data acquisition. In this module, there is the Raspberry Pi 3 microcomputer, model B+, and all the electronic components responsible for the system functioning. The system control and the user interface is done through the embedded software that called SIC (Integrated Control System) that running in Raspberry Pi microcomputer. This software consist of two parts: the machine program developed in C++ language and a user interface program developed in HTML (Fig. 2(a)). The HTML page allows access from any device connected to the system (computers, smartphones, etc…) including remote access when the system connected to a network.

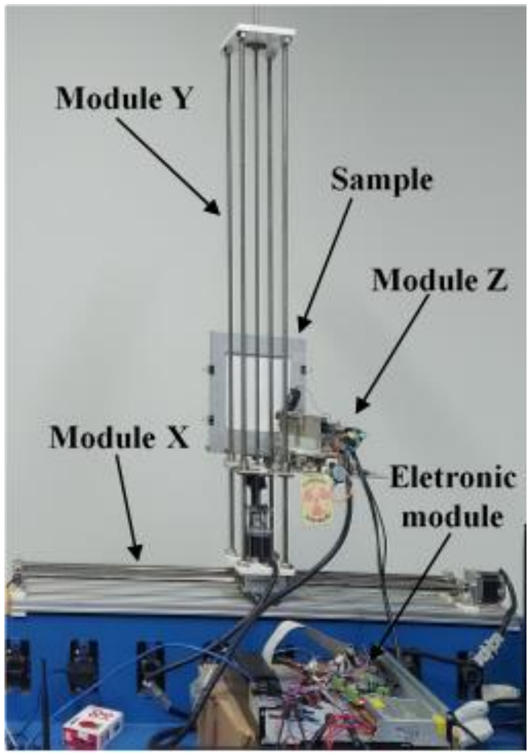

Figure 1: MAXRF system with module X, module Y, module Z and electronic module.

The sample analyzed by the system (Fig.2(b)) consists of a carved wood painting, made by an unknown Brazilian artisan. The dimensions painting have 70 mm x 210 mm and alludes to a woman. The two-dimensional sample mapping were performed at matrix dimensions 70 mm x 210 mm using 35 kV, 100 µA, 5 s for step and 2 mm matrix steps. One measure was obtained on back of unpainted wood surface using 35 kV, 100 µA, 120 s. The results were analyzed using the PyMCA software [10].

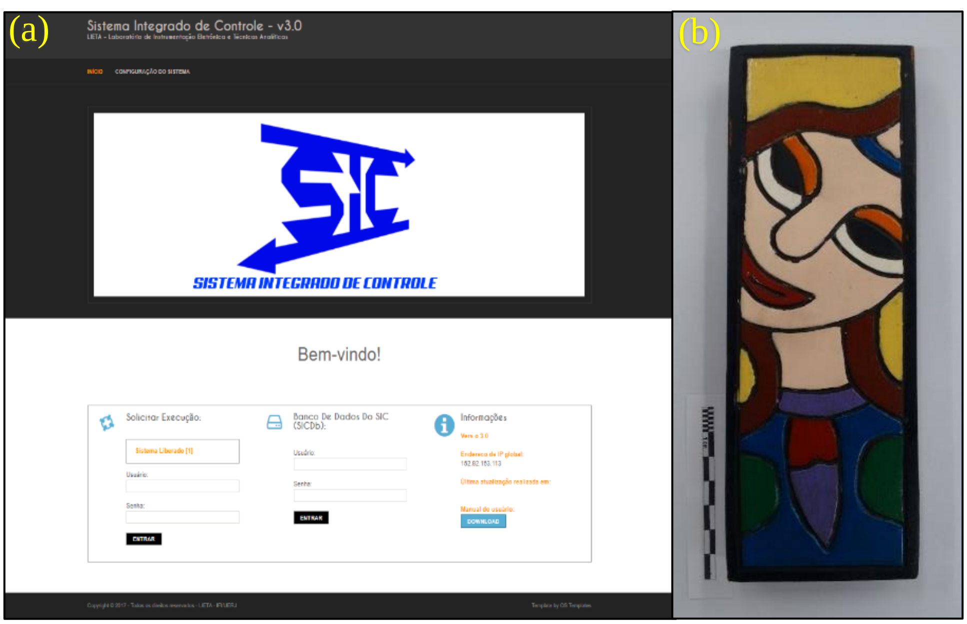

Figure 2: (a) SIC (Control Integrated System) – user interface; (b) Sample analized – wood painting (Brazilian handicraft).

3. Results and Discussion

The results show the presence of the following chemical elements: Ca, Ti, Cr, Fe, Zn, Ni, Co, Cu and Pb, as can be seen in Fig. 3. The calcium element (Fig.3(a)) is usually associated with white pigments, but in this case, this element is associated with the wood carved surface. The measure of the back of unpainted surface show element Ca, so this element is associated naturally the wood. The Fig.3(d) shows that the Zinc element is located in region below the eyes and would be related to the Zinc white (ZnO). One hypothesis is that the artist has also used Titanium white in the white part of the eye as can be seen in Fig.3(b) in addition to the Zinc white. The part of the painting that represents the carnation is contributed by Titanium, Chrome and Lead, Fig.3(b), Fig.3(c) and Fig.3(h), respectively. Skin color probably obtained by mixing orange with white pigment. Orange pigment probably obtained by mixing red and yellow pigment. Lead chromate is a pigment known as Chromium Red ($PbO.PbCrO_4$) which can be mixed with Cobalt yellow ($K_3[Co(NO_2)_6]$ to produce the orange pigment [11][12]. It is mixing Chromium red with Cobalt yellow and adding Titanium white until obtaining the desired tone for the skin color. For this reason, the elements Chromium, Lead and Titanium were detected in the colored part of the skin [13].

The Cobalt element is found in the yellow, blue and reddish pigments of wood paint (Fig.3(f)). In the yellow, the Cobalt can be in the form of Cobalt yellow ($K_3[Co(NO_2)_6]$ mixed with Titanium white to obtain the desired shade of yellow by the artisan. In the blue pigment, are found Copper (Fig.3(g)), Cobalt and Titanium. In this case, probably have the combination of Cobalt blue ($CoAl_2O_4$) mixed with a Copper-based blue pigment and mixed with Titanium white again to achieve the desired blue tone. The brown pigment is associated with Iron (Fig.3(e)). The element Iron is one of the main components of the ocher pigments. The element Nickel (Fig.3(i)) follows an Iron distribution because usually ocher pigments also have traces of Nickel and other metals. The black, purple and green pigments did not present elements that could indicate your compositions by XRF. Probably those pigments were made with organic bases.

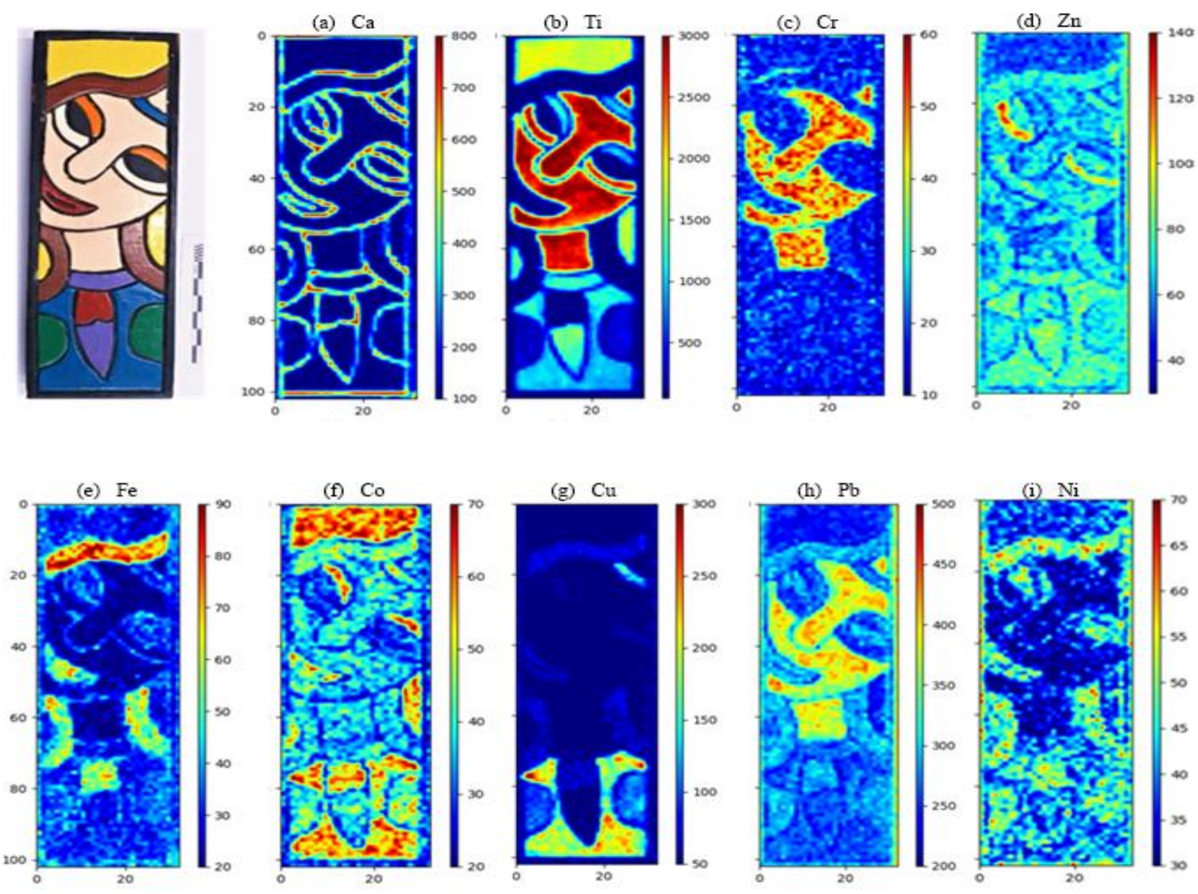

Figure 3: Mapping results showing the chemical elements distributions.

4. Conclusions

The system mechanical and electronic parts connected to each other make the portable system. It being possible to move it to carry out non-destructive analyzes anywhere (museums, churches, laboratories, etc.) inside the car trunk. The results obtained from the laboratory application shows an efficient system, being portable and low-cost compared to commercial systems. The system is able to perform punctual measurements and two-dimensional mappings with excellent resolution and satisfactorily identifying the chemical elements present in each analyzed sample, being possible to characterize the possible pigments used in each one of them.

References

[1] CESAREO, R., CASTELLANO, A., “A Portable Instrument for Energy-dispersive X-ray Fluorescence Analysis of Sulfur”, Nucl. Instrum. Methods Phys. Res., Sect. B, 129, 281–283, 1997.
[2] SZÖKEFALVI-NAGY, Z., DEMETER, I., KOCSONYA, A. et al. “Non-destructive XRF analysis of paintings”, Nuclear Instruments and Methods in Physics Research B v. 226, pp. 53-59, 2004.
[3] APPOLONI, C.R., BLONSKI, M.S., PARREIRA, P.S. “Study of the pigments elementary chemical composition of a painting in process of attribution to Gainsborough employing a portable X-rays fluorescence system”, Nuclear Instruments and Methods in Physics Research A v. 580, pp. 710–713, 2007.
[4] GAMA FILHO, H.S., “Desenvolvimento de um sistema portátil de macro XRF que utiliza aprendizado de máquina para reconhecimento de padrões de cores em pigmentos usados na área de Arqueometria”, Tese, UERJ, Rio de Janeiro, Brazil, 2020.
[5] CAMPOS, P.H.O.V., et al. “A low-cost portable system for elemental mapping by XRF aiming in situ analyses”. Applied Radiation and Isotopes, V. 152, p. 78-85, 2019.
[6] VAN DER SNICKT, G., et al. “In situ macro X-ray fluorescence (MA-XRF) scanning as a non-invasive tool to probe for subsurface modifications in paintings by PP Rubens. Microchemical Journal”. Vol. 138; pp. 238 - 245. 2018.
[7] SAVERWYNS, S. et al., “Macro X-ray fluorescence scanning (MA-XRF) as tool in the authentication of paintings”, Microchemical Journal, Vol. 137, pp 139–147, 2018.
[8] ROMANO, F.P., et al. “Real-time elemental imaging of large dimension paintings with a novel mobile macro X-ray fluorescence (MA-XRF) scanning technique”. Journal of Analytical Atomic Spectrometry. 32(4): p. 773-781. 2017.
[9] DA COSTA, D. S. S., “Desenvolvimento de um sistema de microfluorescência de raios X portátil e automatizado para mapeamento 2D da distribuição elementar em amostras heterogêneas”, Dissertação, UERJ, Rio de Janeiro, Brasil. 2017.
[10] SOLÉ, V.A. et al., A multiplatform code for the analysis of energy-dispersive X-ray fluorescence spectra, Spectrochim. Acta Part B 62, 63-68, 2007.
[11] FERRERO, J.L., ROLDÁN, C., ARDID, M. et al. “X-ray fluorescence analysis of yellow pigments in altarpieces by Valencian artists of the XV and XVI centuries”, Nuclear Instruments and Methods in Physics Research A v. 422, p. 868-873, 1999.
[12] KUHN, H., et al., "Chrome Yellow and Other Chromate Pigments", Artists Pigments, Volume 1, Ed. R. Feller, Cambridge University Press: Cambridge, 1986.
[13] BROSTOFF, L.B., et al., “Preliminary study of a Georgia O'Keeffe pastel drawing using XRF and XRD”, Powder Diffraction, Vol.24(2), pp.1-8, 2009.