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Development of an Open-Source Iterative Framework for the Automated Detection of Medical Radionuclides in Hospitals

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BACKGROUND

When dealing with radioactive substances in a clinical setting, several safety precautions are required. For example, in brachytherapy, radioactive emitters containing ^{125}I and ^{192}Ir must be regularly checked for leaks by taking smear tests. To analyze these samples a gamma spectrometer is used. It allows to identify radioactive nuclides and to determine their activities (decays per second).

However, existing systems used to analyse radioactive materials are tied to costly licensing conditions and only allow the user to work within a manufacturer-specific detector-analysis environment.

AIM

The aim of the work is to develop a fast, practical quality control method of the gamma spectrometer. Therefore, a recently developed framework by Fearn et al. (2022) was analysed and applied on the clinical setting at the academic teaching hospital in Feldkirch, Austria.

MATERIAL & METHODS

As shown in Figure 1, we designed a pipeline for the automated detection and identification of medical radionuclides. For the experimental study, a germanium-semiconductor gamma spectrometer was used. Initially, the dimensions of the detector and geometries were implemented virtually. A multi-radionuclide calibration source from Eckert and Ziegler™ was used for the experimental calibration. As an application example, a smear test was taken from a leaking emitter containing the medical radionuclide ^{192}Ir, as it is commonly used in the brachytherapy.

To analyze the gamma-ray spectrum derived from the detector, a recently developed python module was considered due to its iterative code base and open-source availability. After the obtained dataset was imported into the workspace, the framework was applied to analyse the spectrum. The framework consists of several cornerstones such as peak detection, fitting and labelling.

For the statistical analysis, the identified radionuclide peaks are displayed along with the peak energy, a relative intensity (RI) value, based on the integrated counts under the peak; an adjusted R^2 value as an indication of goodness of fit and the integrated counts per second (CPS). Furthermore, an arbitrary confidence factor (ACF) between 1-3 is shown to ensure the robustness of detected isotope and the full width at half maximum (FWHM). Moreover, the net area of the nuclide and its uncertainty are displayed after the removal of the background noise of the spectrum. Finally, a peak locate report was generated using the commercially available software Genie 2000™ and compared to the outcome of the module presented here for validation.

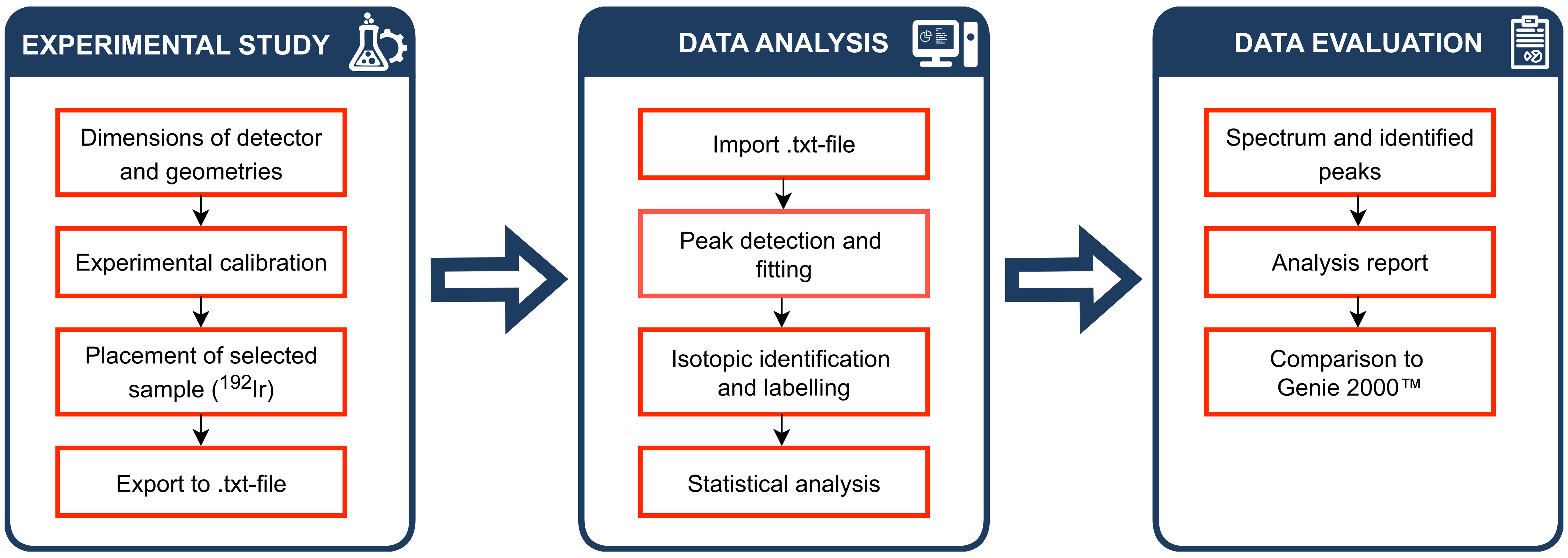

Figure 1: Overview diagram describing the pipeline of the automated detection and evaluation of the isotope identification process.

RESULTS

Initially, the multi-radionuclide calibration source was analyzed, 8 out of 10 isotopes were successfully identified by the python module (Table 1) whereas Genie 2000™ managed to successfully identify each peak. Figure 2 shows the spectrum from the 20 keV to 600 keV energy range of the smear test containing ^{192}Ir. Correctly identified emission peaks are highlighted in green, missed peaks in red.

For each identified peak, the data analysis pipeline automatically performed a statistical evaluation as shown in Table 2. The R^2 of the detected peaks is overall at least greater than or equal to 0.89. The CPS ranges from 0.17-0.47. The overall ACF was set to 2 and the FWHM was within a range of 1.04-1.27 keV. Of all detected peaks, the net area ranged from 155-393 and its uncertainty from 14.2-22.6. The comparison with Genie 2000™ showed that the 4 peaks were correctly identified but 2 smaller peaks at 75.7 and 205.8 keV were missed. Nevertheless, the statistical evaluation of identified nuclides of the module was in good agreement with the analysis report of Genie 2000™.

Isotope	Gamma Energy (keV)	Activity (Bq)
^{133}Ba	**81**	**1,93 x 10^3**
^{57}Co	122	2,01 x 10^3
^{139}Ce	**166**	**1,97 x 10^3**
^{133}Ba	**356**	**1,93 x 10^3**
^{85}Sr	514	9,77 x 10^3
^{137}Cs	**662**	**3,91 x 10^3**
^{54}Mn	**835**	**3,94 x 10^3**
^{88}Y	**898**	**9,73 x 10^3**
^{65}Zn	**1116**	**9,73 x 10^3**
^{88}Y	**1836**	**9,73 x 10^3**

Table 1: Radioactive emitters and activities contained within the Eckert and Ziegler™ multi-radionuclide calibration source. The isotopes successfully identified by the peak identification program of the python module are in bold and highlighted in green.

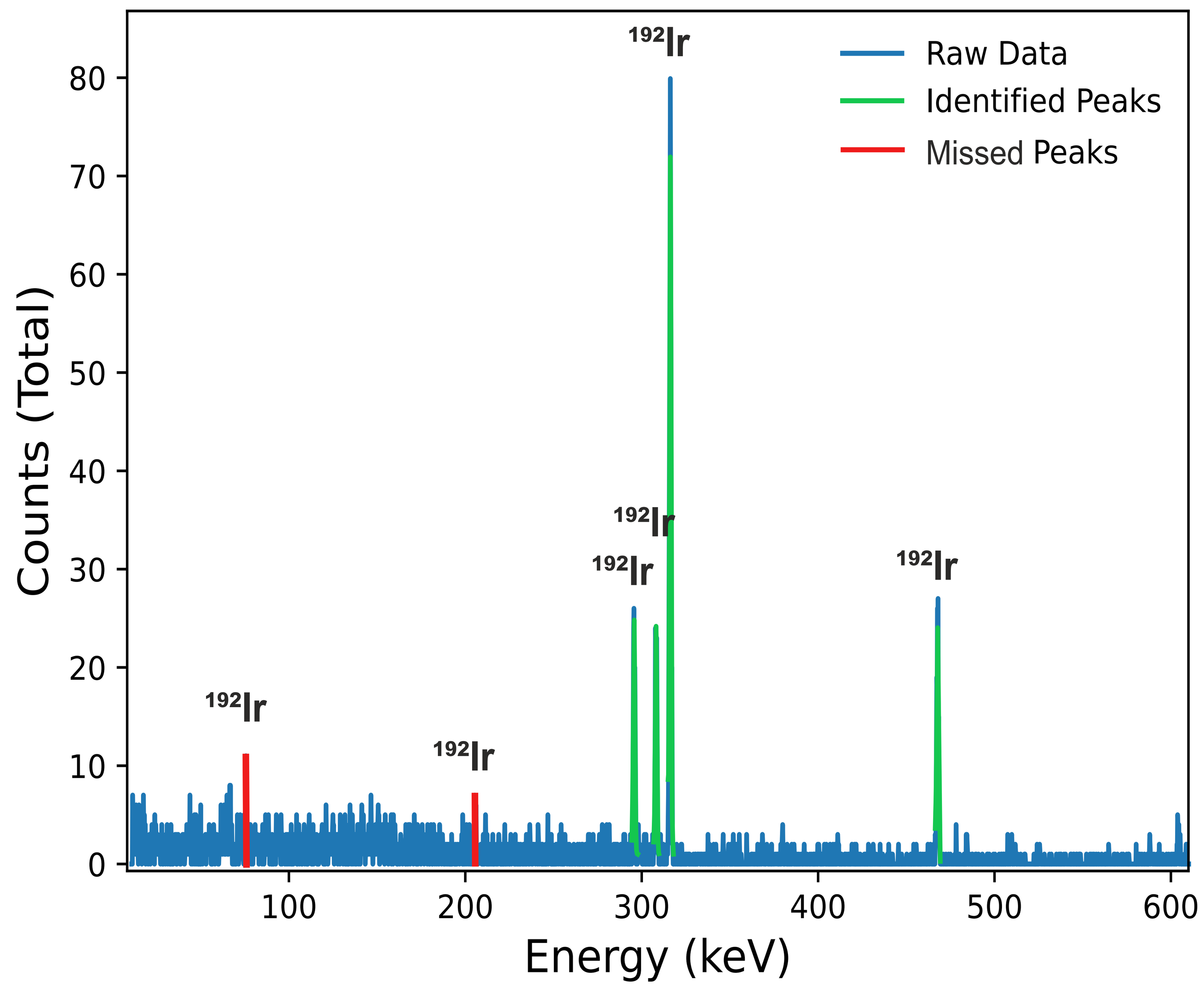

Figure 2: Peak-identified gamma-ray spectra, analyzed after data collection (post-processed) of a smear test containing ^{192}Ir using a germanium-semiconductor gamma spectrometer. Raw data is displayed in blue, identified energy-efficiency corrected peaks in green, missed peaks in red.

Isotope	Energy (keV)	RI (%)	R^2 of fit	CPS	ACF	FWHM (keV)	Net Area	Net Area Uncertainty
^{192}Ir	295.6	39.7	0.94	0.19	2	1.18	155	14.5
^{192}Ir	308.2	37	0.93	0.17	2	1.17	153	14.2
^{192}Ir	316.3	100	0.96	0.47	2	1.04	393	22.6
^{192}Ir	467.7	39.2	0.89	0.18	2	1.27	159	15.3

Table 2: Statistical evaluation of the smear test consisting of ^{192}Ir.

CONCLUSION

The analyzed pipeline shows a promising iterative approach for a simple and time efficient spectral analysis of medical radionuclides in a clinical setting. However, further research needs to be conducted to improve the detection algorithm and eliminate potential error sources.

One general aspect is to increase the sensitivity of the peak detection especially in the lower energy range. For the application in the clinical setting, radionuclides with a short decay time are commonly used. Therefore, the activity (Bq/l) as well as the decay series of each isotope needs to be included into the evaluation.

Nonetheless, the framework developed by Fearn et al. (2022) provides an excellent basis for potential application in clinical settings, as it is open source and easily integrated with many different deployment options and detector types.

[1]Fearn, S.J.; Kaluvan, S.; Scott, T.B.; Martin, P.G. An Open-Source Iterative Python Module for the Automated Identification of Photopeaks in Photon Spectra. *Radiation* 2022, *2*, 193-214. https://doi.org/10.3390/radiation2020014

All authors disclosed no conflict of interest.