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# Development of an automated source holder in IoT for application in industrial process tomography

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## ABSTRACT

Computed tomography technology uses an electromagnetic radiation source or particulate radiation source, to a nalyze / study different samples that can range from living organisms to the most diverse objects (rocks, phanto ms, etc.). The use of the radioactive materials may cause harm to the operator if he is exposed to the source of ra diation, so aiming at the safety of the operator, the objective of this work is to develop an Internet of Things auto mation system for the opening of the Industrial Process Tomography source holder for industrial tomography a pplications. Thus, this system can drive the stepper motors through this platform can be opened at a safe distanc e to the operator, avoiding the operator to take radiation dose to perform this operation. For the IPT project, fiv e source holders were made so that each was positioned diametrically opposite each array of detectors. In this pr oject we used 192Ir sources that have activity of 18,500 MBq and that were produced in the reactor IEA-R1, fro m the neutron bombardment of the pellet containing stable isotope 191Ir. The main characteristics of 192Ir are: half-life of 74.2 days; radiation energy from 0.13 to 0.65 MeV. For the safety of the operator during the opening of the sources, an automated opening system with IoT that can be activated with software installed on the tomog raphy or by a smartphone application  by the MQTT protocol, which makes it possible to be monitored in real ti me at long distance showing the opening and closing status of each source holder.

*Keywords: source holders, Internet of Things, Industrial Process Tomography.*

## 1. **INTRODUCTION**

This work aims the design and manufacture of a source holder to be used in real-time tomography of industrial processes, which was developed in the industrial computed tomography laboratories of the Radiation Technology Center of the Energy and Nuclear Research Institutes (LTCI - CRT / IPEN). Safe for the operator, avoiding the user to take a dose of radiation by performing this operation via Wi-Fi communication.

It was used sources of 192Ir that have activity of 18,500 MBq (500 mCi) and that were produced in the reactor IEA-R1, with approximate power of 4.5 MW to 5 MW, from the neutron bombardment of the tablet containing isotope stable 191Ir, to a flow of approximately $3.45 \times 10^{13}$ n.cm$^{-2}$.s$^{-1}$ [1]. The main characteristics of 192Ir are half-life of 74.2 days; radiation energy from 0.13 to 0.65 MeV [2].

For operator safety during opening of sources, an automated IoT opening system that can be activated with software installed by a smartphone application (.app) by the Message Transporting Telemetry Transport (MQTT) protocol, which enables the monitoring in long-distance real time, showing the opening and closing status of each source holder.

This work has not been possible to have many previous work references because the IoT technology is relatively new compared to other communication technologies and in the field of nuclear technology in machine control applications has not been found so far, seeing that it is a technology which can be highly developed due to the communication being made at safe distances for operators [3].

## 2. **METHODOLOGY**

### 2.1. **Source holder**

According to the geometry of the detector arrangements, defined previously in the tomograph development [3], as can be seen in Figure 1, a detailed study was carried out for the development of

the source holder. Studies to establish parameters (distance, geometry, collimation angle) for making a source holder capable of obtaining the best detection efficiency were performed.

**Figure 2:** *Drawing of the opening angles of the source holder in relation to the detectors. View of one of the five sets of detectors and accessories (A), Detector support set(B).*
Source: LTCI – CTR/IPEN



A



B
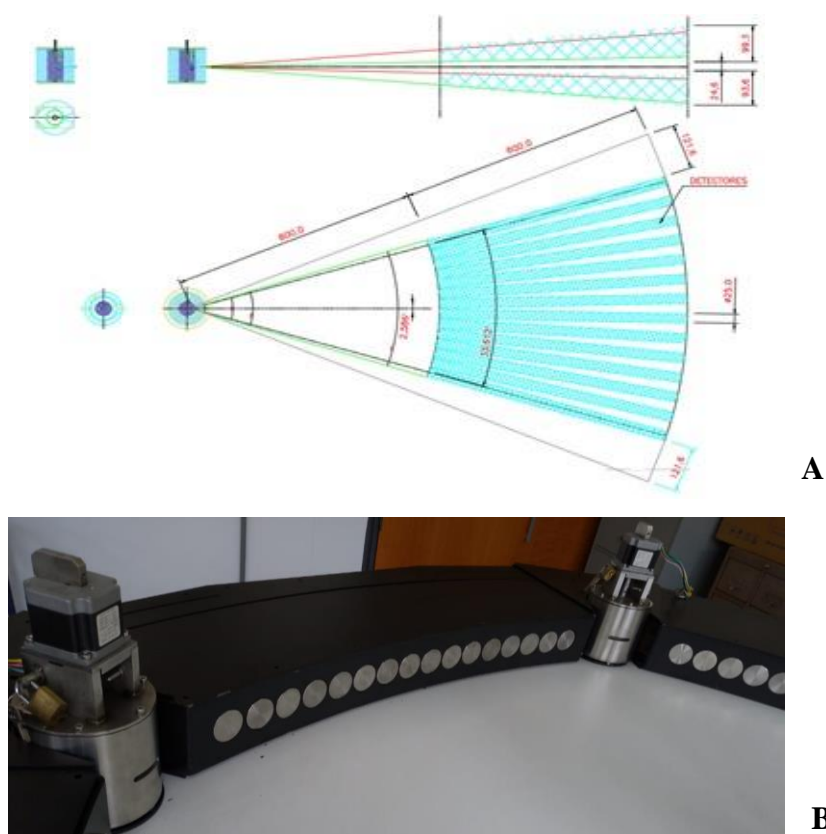
To determine the material to be used in the source holder production, the radiation shielding, and materials thickness were calculated using the equation 1, where $y$ = final activity [Ci], $a$ = initial activity [Ci], $\mu$ = coefficient of attenuation of gamma radiation [cm$^2$.g$^{-1}$], $\rho$ = density of the material [g.cm$^{-3}$], $x$ = thickness of the material [cm] [3].

$$y = a \cdot e^{-\mu.\rho.x} \qquad (1)$$

The radiation activity, out of the source holder was calculated using the equation 2, where $y$ = radiation activity coming out of the shield [Ci], $\Gamma$ = factor of the exposure rate of the radioactive isotope [R.m$^2$ / h.Ci], $a$ = activity of the radioactive source [Ci], $t$ = time of exposure [ minutes], $d$ = distance from the radioactive source [m]. Both forms of the calculus were performed using some C# code routines [3].

$$y = \Gamma \cdot \frac{a \cdot \left(\frac{t+1}{60}\right)}{d^2} \qquad (2)$$

The necessary shielding thickness was based on the density of the material. In this study Lead (Pb), Tungsten (W), and 304 Stainless Steel (Inox-304), were evaluated to be used as shielding and the energy of the radioactive isotopes to be used, which were 60Co, 75Se, 137Cs, and 192Ir. Thus, the source-holder was produced using forged tungsten due to its high density and attenuation to gamma radiation [3, 4].

Visual Studio® was used with the C# programming language to develop the graphic interface of the programs, Figure 3 helps the user to enter information about the radioactive source and the type of shielding material, so that the program itself makes the relevant calculations [3].

**Figure 3 -** *Interface software for calculating the radiation dose operator can take (A), calculating the shield to check for leakage of radiation (B)*
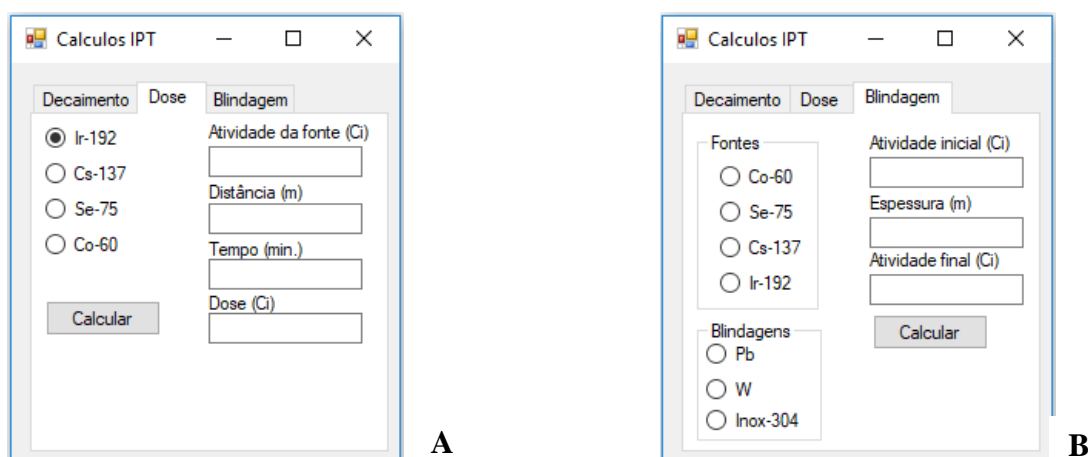
Five source holders were designed and built to be positioned diametrically opposite each detector array. A detailed source support draws and picture are presented in Figure 4 and 5. In the Figure 4A the sectional view of the sources holder, and Figure 4B present the radioactive source spot area in the source holder in detail, as can be seen in this Figure [3].

**Figure 4:** *Technical drawing of the source holder with tungsten shield for the tomography assembly portable industrial real-time processes (A), Sectional view of the source holders (B).*
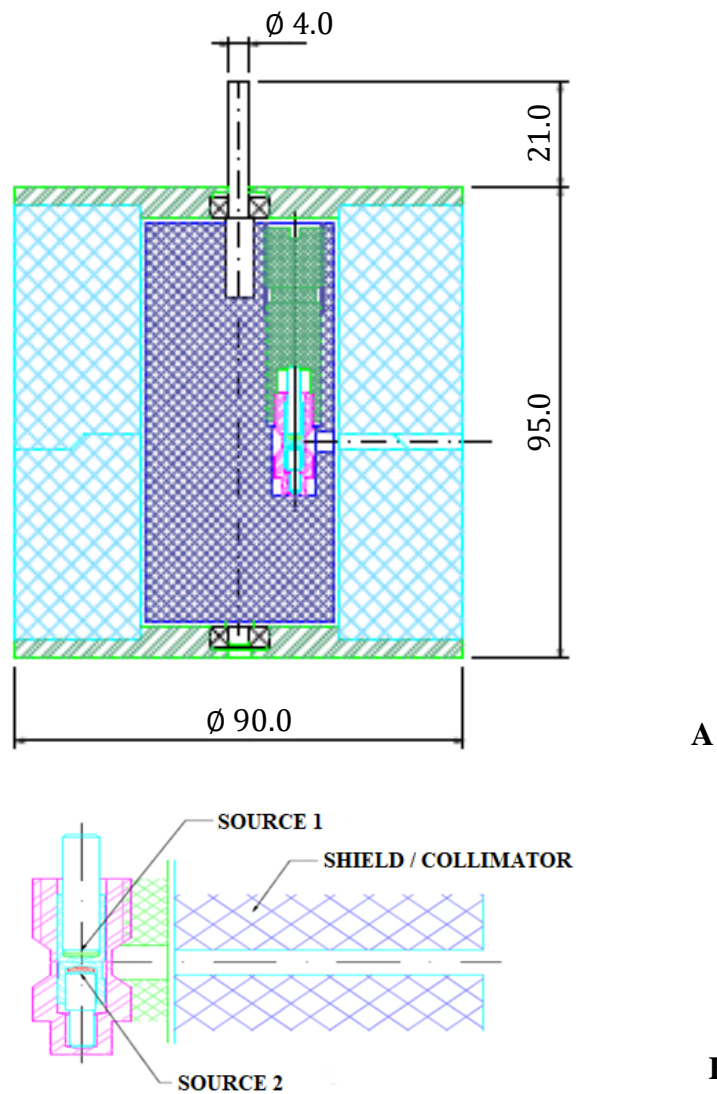Source: LTCI – CTR/IPEN

Figure 5A presents a picture of the source holder with the stepper motor coupled, and the 192Ir sources used for this project is shown in Figure 5B [3].

**Figure 5:** *The photo of the source holder made with capacity for two sources (A) and photo of radioactive sources (B).*
Source: LTCI – CTR/IPEN



**A**                                                                                                          **B**

## 2.2. Stepper motor

The stepper motor chosen for this project was the KTC-HT23-394 from Kalatec® due to its size, which fits perfectly in the source holder. Each stepper motor was configured to have their windings in series to provide a lower electric current passing through the electronic system [5] The activation of each stepper motors is performed by the operator, in a smartphone application. The electrical characteristics of the motor are described in Table 1.

**Table 1: Stepper motor characteristics**

| Motor connection | Minimum static torque (N.m) | Step (angle) | Volts (voltage) | Amps (current DC) | Ohms (resistance) | mH (inductance) | Rotor inertia (g.cm2) | Motor weight (kg) |
|---|---|---|---|---|---|---|---|---|
| Series | 0.540 | 1.8 | 4.0 | 1.41 | 2.8 | 5.6 | 120 | 0.45 |
| Parallel | 0.540 | 1.8 | 2.0 | 2.38 | 0.7 | 1.4 | 120 | 0.45 |
| Unipolar | 0.538 | 1.8 | 2.8 | 2.00 | 1.4 | 1.4 | 120 | 0.45 |

Source: KALATEC, 2018

### 2.3. ESP32s

In this work the NodeMCU-32s version is a development board based on the ESP-WROOM-3232s, which is a highly technological electronic component specially developed to connect robotic projects or residential automation and small industrial projects to the Internet, easily and mainly low cost.

In this module, besides the ESP32s, it has a crystal of 40MHz in addition to the crystals of 160MHz and 240MHz, built-in antenna and micro USB port for power and programming, plus 36 General Purpose Input / Output (GPIO) pins, Analog-to-Digital Converter with 12 bits of resolution, 2 Digital-to-Analog Converter and with 8-bit resolution, Wi-Fi 802.11 b/g /n, Bluetooth V4.2 and dual core 32-bit LX microprocessor [6].

### 2.4. Programming of the motors of opening / closing of the sources system

An automated system using an Internet of Things (IoT) concept was developed aiming the operator's safety during the opening and closing of the source holder. This system may be activated via software installed on the computer or by a smartphone application, with security protocols and data encryption, Message Queuing Telemetry Transport (MQTT). Programming codes was written in the Arduino Integrated Development Environment (IDE) [3, 7 - 9].

This automated system enables monitoring of the stepping motor in real-time and at long distance, once the opening and closing status of each source holder separately is showed for the operator [3, 7 - 9].

The MQTT protocol and the application design platform, *MQTT DASH* for smartphone, communicate between the ESP32s module and the smartphone via the internet using a broker, that is a web data manager system [8, 9], which enables opening and closure of the power supplies, either simultaneously or separately, besides performing all status verificatios.

The software for managing the opening and closing system of the sources was developed on a freeware application platform, available on the internet. In MQTT DASH applications, the data management is handled by the *Cloud MQTT* server [3], Figure 6.

**Figure 6:** *Configuration screen on the Cloud MQTT website.*
Source: Cloud MQTT, 2018
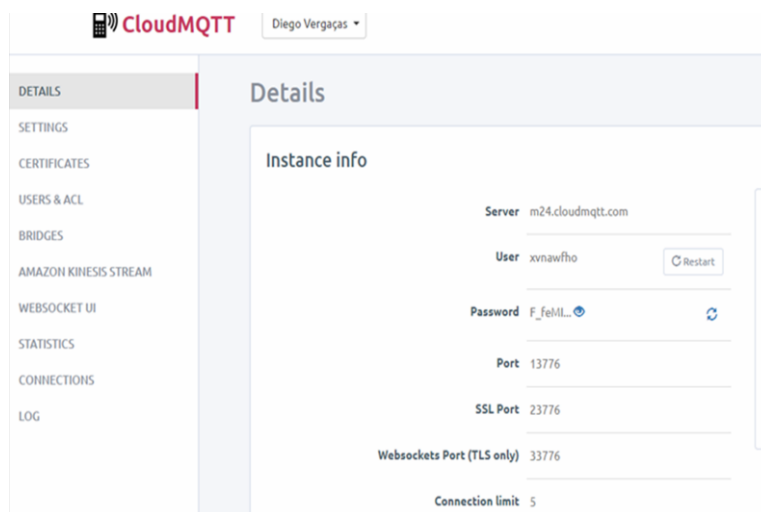


Using the internet, the *Cloud MQTT* provides some data, such as server, user, password, and ports, necessary to run the ESP32s application. Thus, the programming code are configured, and then they may communicate with the cloud. [3, 8].

## 3. **RESULTS AND DISCUSSION**

### 3.1. **Engine control module**

The stepper motor control module was developed with the same standard of the pre-drilled plate, as can been seen in the Figure 7, ESP32s is coupled to a ULN2803 drive controller for each motor of its respective source holder. This whole system uses a voltage of 5 volts [3].

**Figure 7:** *Stepper motor control module.*
Source: LTCI – CTR/IPEN
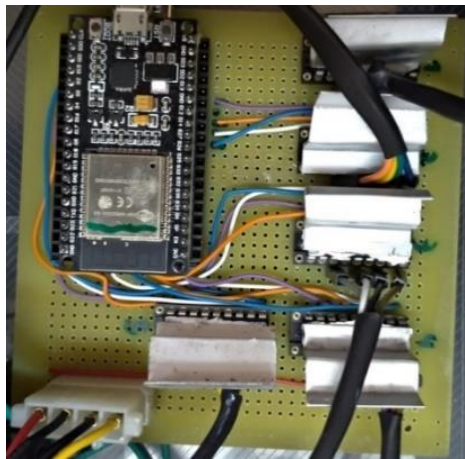


The stepper motor control module had an effective control, but some heat on the ULN2803 drive was observed. This is due to the current that is trying to flow through this component which is rated to a collector current of 0.5 A only. This heat process occurs because the motor coils demand of 1.5 A, and the internal diode clamps this current to 0.5 A [3]. This problem was solved an aluminum sinks on top of integrated circuits and a mini fan cooler.

### 3.2. **Opening and closing source holder system software**

From the data provided by *Cloud MQTT* the application is configured to  communicate with the cloud, so the communication through the internet, using the MQTT protocol with the ESP32s to controlling and monitoring of the stepper motors of the source holder is initiated.

The software interface for managing the system is shown in Figure 8. As can be seen in the application screen, there are symbols representing each of holder. Figure 8A indicates that the source holders are closed, and Figure 8B, containing the highlighted symbols, represent that the radioactive sources are exposed, so the source holders are opened [3, 10, 11].

**Figure 8:** *Screenshots of the app showing closed source holders (A), open source holders (B).*
Source: LTCI – CTR/IPEN
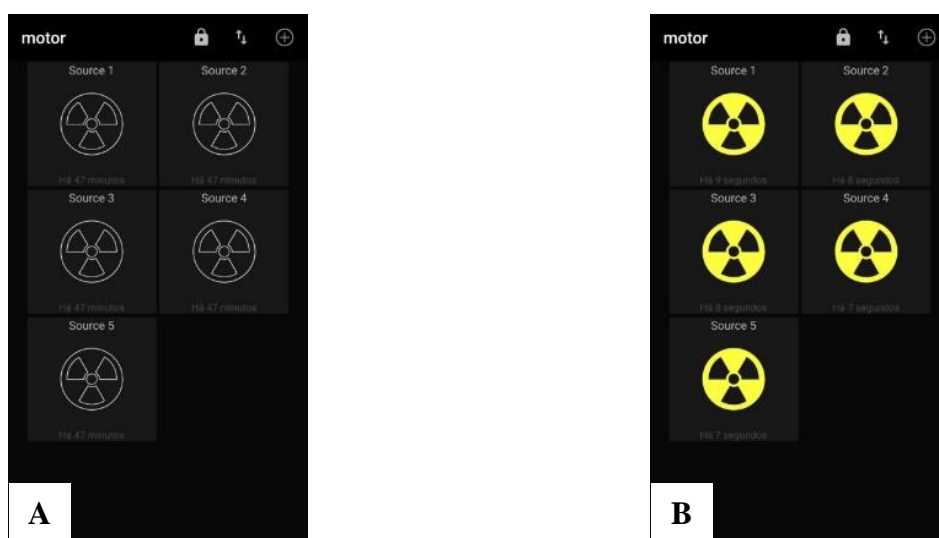


## 4. **CONCLUSIONS**

The use of the MQTT protocol is a form of communication with easy programming that allows quick access for data transfer between smartphones and electronic systems with IoT technology as the one used in this work, ESP32s.

The motors module has an effective control but with a heating in the ULN2803 driver was noted, probably due the voltage and current in the system, but this problem was easily solved adding aluminum sinks on top of the integrated circuits and a cooler.

The automatization of the source holder system for industrial process tomography, as performed in this work was effective, but major studies and developments for the whole tomographic system will be necessary.

## ACKNOWLEDGEMENTS

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