XShields: Cross-platform Application for the Design of Shields against Ionizing Radiation

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Abstract. In many cases medical diagnosis is based on information obtained through a process involving the emission of different forms of ionizing radiation. The safety of the medical staff and patients exposed to ionizing radiation is highly dependent on the proper design of the shielding used in the laboratory. Therefore, the authors propose a multi-platform application supporting such a design through the computation of the critical parameters of shielding. The specific requirements for shielding are defined by government authorities so the algorithm must comply with all the written standards. The application was implemented using Xamarin. Forms for cross-platform development. The results obtained with the use of the developed tool were compared with those calculated manually for the design of stationary shields developed, deployed, and validated by local inspection.

Introduction

The increased popularity of smartphones among the population resulted in the development of dedicated mobile applications supporting work in many disciplines such as physics (Chekanov et al., 2017), chemistry (Dua et al., 2012; Szidarovszky et al., 2018), medicine (Zhenga et al., 2007), agriculture (Gonzalez Perea et al., 2017), and archaeology (Oliveroa et al., 2019; Weaver et al., 2011). In particular, Olivero et al. (2019) presented a review of mobile applications designed and built for the purpose of hospital management.

However, in hospitals and smaller medical practices, there are other areas which need technological support. One of them is safety. For instance,

medical diagnosis based is in many cases on information obtained through a process involving the emission of different forms of ionizing radiation. The safety of the medical staff and patients exposed to ionizing radiation is highly dependent on the proper design of shielding used in the laboratory.

Although tools simulating the effects of ionizing radiation exist (Emmanuel & Raghavan, 2016; Infantino et al., 2015; Pourrouquet et al., 2011) there is still the need to develop a handy application for supporting professionals (usually physicists or medical physicist), which would help in fast and easy computations, enabling the selection of the most appropriate shielding. In this way, the safety of patients and medical staff would be ensured. Different countries have their own standards regarding the protection of people (UK Statutory Instruments, Health and Safety, 1999; Health and Safety Executive, 2018; German Standards, 1994; Korchin, 2005; US Standards, 2004) against above norm doses of radiation. Therefore, modern and robust solutions are needed to design the means of such protection. Consequently, the scope of this work was to use Xamarin.Forms to build the cross-platform application in question, supporting such a design through the computation of the critical parameters of shielding.

As the development of multi-platform applications has become a flowering branch of IT, thus software vendors started to deliver dedicated developer environments. Regarding Microsoft Visual Studio, one of the most popular tools globally (Kumar, 2017), the Xamarin framework was included in its 2017 version. Its component, called Xamarin.Forms (Petzold, 2015), allows the programmer to write shared user interface code using XAML scripts and C#, which map to native controls on platforms such as Windows 10, Android, and iOS.

Mathematical Formulation of the Requirement

The current requirements of the Polish authorities were taken into account so that the shielding designed with the use of the authors' app complies with all of them.

First of all, it complies with the Polish standard "Protective materials and devices against X and gamma rays – calculation of fixed screens". The method for the calculation of "fixed screens" was applied (Polish Standards, 1986). Only those shields that concern X-ray radiation between 50–500 kV were taken into account in this study. However, it is possible to also include gamma radiation and bremsstrahlung (brake radiation)

Sr^{90} - Y^{90} , Tm^{170} in future studies. In order to create software, the equations presented below (Polish Standards, 1986) were used:

$$t_1 = n \cdot t_0 \quad (1)$$

t_1 – maximum working time of the radiation source during week on a single shift (s);

n – number of exposures per week;

t_0 – single exposure time (s);

$$t = T \cdot U \cdot t_1 \quad (2)$$

t – time of exposure during a week (s);

T – coefficient determining the probability of people staying in a sheltered place;

U – coefficient determining the probability of directing a useful radiation beam towards the calculated shield;

$$k = \frac{D' \cdot I \cdot t}{D \cdot l^2} \cdot y \quad (3)$$

$$C_1 = \frac{D \cdot l^2}{t \cdot I} \quad (4)$$

$$f_{A...Z} = l_{A...Z} + f_1 \quad (5)$$

$$\frac{f_1^2}{s_1} = \frac{f_{A...Z}^2}{s_{A...Z}} \gg s_{A...Z} = \frac{(f_{A...Z})^2 \cdot s_1}{f_1^2} \quad (6)$$

$$C_2 = \frac{D \cdot l^2 \cdot f_{A...Z}^2}{t \cdot I \cdot s_{A...Z}} \frac{D \cdot l^2 \cdot f_{A...Z}^2}{t \cdot I \cdot s_{A...Z}} \quad (7)$$

D' – dose rate at a distance of 1 m from the focal point of the lamp converted to 1 mA current $\left(\frac{\text{cGy} \cdot \text{m}^2}{\text{min} \cdot \text{mA}}\right)$;

D – allowed weekly dose radiation: for k $D(\text{cGy})$, for C_1 and C_2 $D(\mu\text{Gy})$;

y – coefficient of weakness in tissue;

f_1 – distance of the X-ray focus from the patient/person (m);

$f_{A...Z}$ – distance of the object scattering radiation from the x-ray focus (m);

$l_{A...Z}$ – the smallest distance between the object that dissipates the radiation and the place covered by the set working conditions (m);

I – nominal anode current of the X-ray tube (mA);

s_1 – surface of the scattering object that is subject to radiation (m^2);

$s_{A...Z}$ – projection of the surface of the scattering object that is subject to radiation, on a plane perpendicular to the direction of the primary beam of radiation at a distance $f_{A...Z}$ (m^2);

$A...Z$ – example shield name;

Figure 1. The positioning scheme of the proposed X-ray device and the design of fixed shields (A, B1, B2, C, D1, D2, DRZWI 1, DRZWI 2, OKNO)

Figure 1 shows an example scheme with X-ray device positioning and the design of fixed shields. The position of the X-ray device and the direction of the primary beam radiation depends on the type of the X-ray device, the construction of the X-ray laboratory and user preferences. In any case, it needs to be remembered that the local regulations need to be taken into consideration.

Software Development and Testing

Three classes for storing parameter values and the implemented methods were created. The basic class containing the fields for initial parameters and the introductory computations was developed and previously used in (Szumielewicz et al., 2018). The following two classes were designed and implemented separately for primary ionizing radiation and scattered ionizing radiation. The classes mentioned above are independent of the Graphical User Interface (GUI) code so computational routines can be easily incorporated in other projects.

The GUI consists of a set of pages (screens) built in the Xamarin.Forms project. In this kind of project, each GUI page is defined in XAML script

(Fustino, 2018), whereas page-related methods (through event handlers) were coded in C#.

Debugging was performed on a local machine running Windows 10 as well as on an external mobile device with the Android operating system. The mobile phone used was HUAWEI P10 lite. The screen content and graphic alignment was optimized for the screen resolution of the mobile device.

Regarding the tests of numerical accuracy, they were similar to those performed in our previous study (Szumielewicz et al., 2018). The results obtained using the developed tool were compared with those calculated manually. The numbers presented in Figure 2–6 correspond to the real-life case of shield design for a local X-ray laboratory used in dentistry.

Multiplatform Application

The application's GUI consists of screens that are mainly used as forms for entering parameters and to display the values returned by the algorithms. The main page of the XShields application contains several parameters of the device: nominal anode current of the X-ray tube, the time of single exposure, voltage on the X-ray tube, number of exposures per week, total filtration.

The figure displays two side-by-side screenshots of the XShields application interface on a mobile device. Both screens show the status bar at the top with 'T-Mobile.pl', signal strength, 82% battery, and the time 09:04.

The left screenshot is titled 'XShields' and 'Device Parameters'. It contains the following input fields and buttons:

- Anode current: I [mA] with a value of 7.
- Single exposure time: t0 [s] with a value of 1.
- A button labeled 'CHANGE TO CURRENT-TIME LOAD'.
- Anode voltage: U [keV] with a value of 65.
- Number of exposures per week: n with a value of 10.
- Total filtering [mmAl] with a value of 2.5.
- A button labeled 'NEXT - FACTORS'.

The right screenshot is also titled 'XShields' and 'Probability parameters'. It contains the following input fields and buttons:

- Factor determining the probability of people staying in a shielded place: T with a value of 0.05.
- Coefficient determining the probability of directing the useful radiation beam towards the calculated shield: U.
- A button labeled 'NEXT - ACCEPTABLE DOSE'.

Figure 2. XShields application screens with fields for entering the initial parameters used in computations

The figure shows two side-by-side screenshots of the XShields application interface. Both screens have a dark header with a back arrow and the title 'XShields'. The status bar at the top shows 'T-Mobile.pl', signal strength, 82% battery, and the time 09:05.

Left Screenshot: Further parameters

- Section: Further parameters
- Field: Permissible dose of radiation [uGy/week] with value **8.8**
- Field: The smallest distance of the lamp focus from the sheltered place under specified operating conditions: l [m] with value **2.5**
- Buttons: **CALCULATE SCATTERING RADIATION** and **CALCULATE PRIMARY RADIATION**

Right Screenshot: Calculation of scattering radiation

- Section: Calculation of scattering radiation
- Field: Distance of the object scattering radiation from the focus of the X-ray tube calculated in meters: f [m] with value **0.2**
- Field: The surface of the scattering object that is subjected to radiation: s [m2] with value **0.0025**
- Button: **SHOW RESULTS**

Figure 3. XShields application screens with fields for entering parameters related to scattered ionizing radiation

The figure shows two side-by-side screenshots of the XShields application interface. Both screens have a dark header with a back arrow and the title 'XShields'. The status bar at the top shows 'T-Mobile.pl', signal strength, 62% battery, and the time 09:05.

Left Screenshot: Computing results for scattered radiation

- Section: Computing results for scattered radiation
- Field: Reduced dose rate C1: 56122
- Field: Required lead shield thickness [mm]: 0.1
- Field: Reduced dose rate C2: 779472
- Field: Required lead shield thickness [mm]: 0.1
- Button: **SHOW RESULTS FOR ALTERNATIVE SHIELDS**

Right Screenshot: Required thicknesses for alternative shields

- Section: Required thicknesses for alternative shields
- Text: *Density barite concrete 3.2 g*cm-3: 0.9
- Text: *Density barite concrete 2.7 g*cm-3: 1.75
- Text: *Density concrete 2.1 / 2.2 g*cm-3: 9.85
- Text: **Density concrete 2.1 g*cm-3: 9.9
- Text: **Gas-concrete 0.68g *cm-3: 40.5
- Text: ** Plaster concrete 0.84 g*cm-3: 24.3
- Button: **NEXT**
- Text: *PN-86/J-80001
- Text: **Roentgenverordnung 814.542.1

Figure 4. Additional screens of the XShields application with results for scattered ionizing radiation and for selected alternative shields

The next screen contains two parameters: T – coefficient determining the probability of people staying in a sheltered place and U – coefficient determining the probability of directing a useful radiation beam in the direction of the calculated shield (Figure 2).

Figure 5. Additional screens of XShields application with results for primary ionizing radiation and for selected alternative shields

Figure 2 presents screens with the following parameters: allowable weekly dose radiation and the smallest distance of the object that dissipates the radiation from the place covered in the set working conditions. Here one of two options can be changed: primary ionizing radiation or scattered ionizing radiation; then the distance of the object scattering radiation from the X-ray focus and the surface of the scattering object that is subject to radiation are entered. After these steps, it is possible to show the results of calculation for the scatter radiation shield made of lead or alternative material (Figure 3). If the user would prefer to calculate only primary ionizing radiation, then parameters such as tissue thickness and external filtration must be added. The next step allows to show the results of the calculation for the shield made of lead or alternative materials (Figure 4). Similarly, the additional screens of the XShields application with the results for primary ionizing radiation and the results for selected alternative shields are shown in Figure 5.

Conclusions

In this work, the cross-platform application to support the design process of shielding against X-ray ionizing radiation was developed and tested in the Polish reality. The obtained results, although still at an initial stage,

are promising. All the specific requirements of the Polish regulations were incorporated so the application generated results that comply with the formal requirements necessary for inspector approval. The application was implemented using Xamarin.Forms, which ensured fast deployment on Windows 10, Android, and iOS operating systems. The results obtained with the use of the developed tool were compared with those calculated manually for the design of stationary shields, developed, deployed, and validated by local inspection.

The authors are planning to develop an improved version in strict cooperation with labs (Fabry et al., 2013). For instance, visualization could be similar to that depicted in Figure 1. It would take into account the geometry of the facility and the location of the radiation sources, enabling the optimization of the shielding construction.

Further Research Plans

Future work will be concerned with creating a system for radiologists using Microsoft Power Apps (Leung, 2017). This is a cloud-based service characterized by easy development, extension, and update of the resulting application. It enables easy distribution of the application to users within organizations such as hospitals or radiology associations. It should be mentioned that the MS Power Apps application may be run on devices with Windows 10, Android, or iOS operating system.

The authors are also planning to develop a more versatile system, which could be applied in other countries and use other norms.

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