SEMI-AUTOMATIC POSITIONING OF THE PROTECTIVE SCREEN BASED ON INTEGRATION WITH A C-ARM X-RAY DEVICE

by

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In fluoroscopy guided interventional procedures, a ceiling suspended screen is used to protect personnel for scattered X-ray radiation arising from patient treatment. The correct positioning of the screen is crucial for proper occupational radiation protection. The proposed solution in this paper provides reliable and efficient protection from scattered radiation, based on an X-ray device and the protective screen merging into one system via an appropriate interface. After the initial manual positioning, automatic repositioning of the screen is executed, by curving the screen laterally, clockwise or counterclockwise, and then with the upper or lower edge forward. All potential clinical situations were analyzed, considering the need for screen position correction: the semi-automatic solution is designed and realized to follow medical procedure in order to maintain an efficient level of staff radiation protection. Furthermore, the assessment of the occupational radiation dose, provided for screen position optimization, will be included into the radiation dose structural report. With application of the universal interface, the presented solution can be applied not only to newly manufactured ones, but to existing C-arm X-ray devices as well.

Key words: protective screen, X-ray device, integration, semi-automatic positioning, occupational dose assessment

INTRODUCTION

Radiation exposure of staff performing fluoroscopy guided procedures in radiology and cardiology is among the highest occupational exposure in medicine. Assessment of the occupational radiation dose in these interventional procedures [1-3], is based on direct measurement of suitable operational dosimetry quantities (especially in Hp(3) [4-8]) or computational dosimetry methods as Monte Carlo simulations [9-14]. This is one of the most important topics in radiation protection of personnel during medical application of ionizing radiation, including PET-CT diagnostics [15-18]. A major source of occupational exposure here is radiation scattered from the patient [2, 8, 10, 11, 19-21]. In order to keep the radiation dose as low as possible, suitable personal and collective protective tools must be used, including the use of ceiling suspended screens. The correct position of a ceiling suspended screen is essential to achieve adequate staff protection [22-25]. Serious strides have been made to improve X-ray diagnostic devices to emit less radiation [26, 27] but, contrarily, the X-ray systems tend to be more complex and sophisticated. Clear guidelines have been written and constantly adapted and improved [28-32].

Protective lead transparent screens have been used as protection against ionizing radiation in medical practice for over 100 years [33, 34]. The shape, dimensions, displacement mechanisms, finishing (rounded edges *etc.*), materials have been perfected. Regarding current development of dose reduction strategies, considering a ceiling-suspended protective screen, an approach for achieving significant progress is presented. Namely, at present the screen is manually positioned and this position does not change during the intervention, regardless of whether the possible change in conditions (there is no communication between the screen and the C-arm X-ray device) also changed the distribution of scattered radiation [1, 4, 9, 22-25, 35]. It surely could be improved with the realization of a conceptual solution of screen managing, repositioning and controlling [36, 37], based on integration of the X-ray device and the screen into a single system.

Automatic control, in order to most effectively position the structural protection against ionizing radiation, has already been applied, such as an X-ray imaging system which has two independently articulated arms, supporting X-ray tube and X-ray detector [38], respectively, but not in the field of interventional

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X-ray procedures, where the problem is complex and layered, due to the fact that their performance requires adequate working space between the patient's body and the detector and that the radiation source and the patient table can move during the intervention. Research in this domain goes in the direction of improving shielding efficiency or introducing additional barriers. In the first case, connecting additional drapes, attention is required to avoid placing the drapes within the primary beam, which may increase patient and operator exposure [1], at the lower end of the screen seemed to be best [39, 40]. The other approach involves the use of an additional mobile protection system [41, 42] – which should not be viewed competitively with the present invention, or the concept of additional protection of the first (the most exposed) operator [43, 44]. There have also been attempts to incorporate additional protection against the radiation source [45] (they have several disadvantages, such as collisions in oblique projections, the impossibility of implementation with flat panel detectors, the impact on the medical image – artifacts, the lack of visual contact of the operators with the patient).

The objective of this work is to improve occupational radiation protection in fluoroscopy guided interventional procedures related to the concept of the patented solution [36, 37] for optimized semi-automated (ceiling suspended) screen positioning.

PROTECTIVE SCREEN INTEGRATED WITH THE C-ARM X-RAY DEVICE

The proposed solution [36, 37] connects the X-ray device and the screen into one system, in such a way that the screen is part of the device or there is a special device (screen with a control unit) that connects the screen to the X-ray device via the appropriate interface.

One of existing standard designs of the (ceiling-suspended) protective screen (fig. 1, [46]) is used, with a body shaped cut-out for better positioning [5, 22, 23, 31] above the patient, which has the required degrees of freedom of movement (with moving mechanisms in joints A, B, and C so that through the moving mechanism in joint A the screen can rotate around the y-axis clockwise (CW) or counterclockwise (CC), and through moving mechanisms in the joints B and C, the screen can be moved with the upper edge forward (FM) or with lower edge forward (BM) around the X-axis.

It is envisaged that, at first, which is current *first and last* practice, the screen is set manually, but then the automatic screen repositioning should be activated, which should lead to curving the shield laterally by the appropriate angle in a clockwise/counterclockwise direction and, directly after that, curving the shield by the appropriate angle around x-axis, with the upper edge forward/lower edge forward.

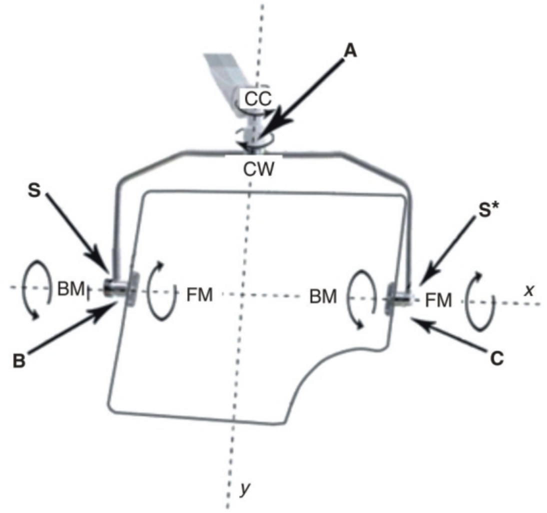


Figure 1. Display of the displacement of the protective screen laterally in the clockwise (CW)/counterclockwise (CC) direction, around the *y*-axis, *i. e.* the upper edge forward (FM)/the lower edge forward (BM) movement around the *x*-axis. The S and S* are predicted push buttons for manual unlocking/locking

Besides the initial phase, before the start of clinical work, the solution considers cases of importance to correct the position of the screen in real time, during the intervention procedure, as well as related necessary conditions and the decisions about manner for doing so, in accordance with potential clinical situations. The fundamental principles of realization of automatic screen control are described in detail by the patent documentation [36], including providing a solution to the problem of collision of the screen with the patient's body and urgent safety aspects.

The microcomputer, through the software for the assessment of optimal angulation, in order to most effectively protect all occupationally exposed persons [1, 2, 6, 9, 10, 29, 30], processes the following input data:

1. the current position of the screen in space (including the corresponding curvatures in the two axes (fig. 1),
2. information on the distribution of scattered radiation, for all reference points and all angulations [10-12, 18-20],
3. the current angulation of the integrated system, which consists of the X-ray tube and the detector, in relation to the central axis of the patient's table – in multiple planes,
4. the current position of the patient table – which can be moved vertically (up and down) as standard, and depending on the model of the device – horizontally and angularly,
5. mass and height of the patient [47, 48],
6. geometric scheme that corresponds to the positioning of the operators (the solution stipulates that it is necessary to have appropriate, clearly vis-

ible markings on the floor, in accordance with the scheme, which indicate where the staff should be positioned (several options, considering the type of procedure and mentioned internal planning decisions), and

7. operator heights (correspond to the geometric scheme: the basic, minimum number of operators provided for a certain medical procedure are processed) [49].

Information on the distribution of scattered radiation for all reference points and all angulations is defined before clinical work and the corresponding values are changed only in case of inconsistency, after off-schedule or regular dosimetric examinations, whereby a control set of measurements would determine the necessity to complete the measuring process. The entry of this data is intended for a site medical physicist or dosimetry service, in a special software mode, while the entry of data 5, 6, and 7 are performed in the internal clinical mode, by the department employees, before the start of the intervention procedure, thus establishing the software initialization of the integrated system consisting of an X-ray device and the screen, which is a prerequisite for the operational work of the system and, consequently, the starting fluoroscopy guided procedure itself [36, 37].

The subject screen control also includes an unlock/lock button (incorporated into or added to the command board) and safety redundant buttons (one certainly positioned in joint B, on the side where the physician and medical technician are usually located during the intervention (marked S in fig. 1), but optionally also in joint C screen (marked S*, fig. 1).

As already mentioned, it is envisaged that, initially, as before, the screen is set manually and then, after the calculation, the presented angular movements are performed and controlled via an appropriate electronic circuit [36], with independent automatic control lines, especially taking into account potential collisions. This brings the screen to the reference position. Fluoroscopy is disabled, *i. e.*, the X-ray tube cannot emit radiation until the screen is blocked. The screen remains in the locked, stable state, as long as there is no need to change:

– the angulation of the system consisted of the X-ray tube and the detector, in relation to the central axis of the patient table and/or the corresponding spatial plane in which the X-ray tube-detector system is positioned, or
– the set position of the patient table.

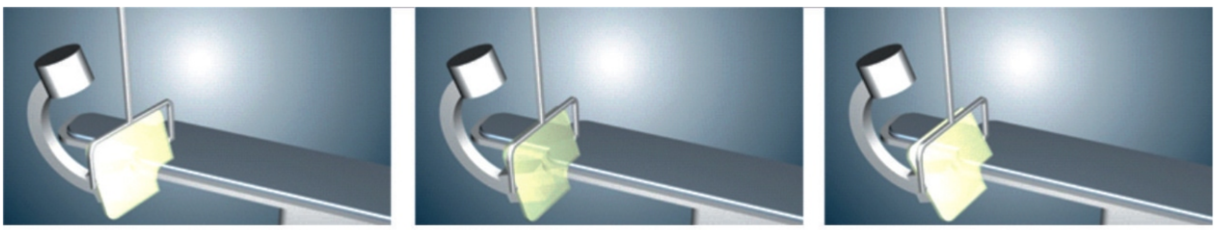
The flow control diagram is made [36], which covers all the previous actions, from entering the necessary data, through system initialization, testing information about the status of the described relevant parameters (which the microcomputer receives in real time) and relevant screen control as a result of their change, external commands depending on the clinical situation and completion (study closure).

The animation [37], continuously followed by explanations in the subtitles, shows the process of automatic repositioning of the screen, with dynamic monitoring of changes through relevant status indicators. Figures 2 and 3 present examples of indications and relevant solutions of screen management, exstracted from the movie [37].

The application of the solution stipulates that the structural report on the radiation dose will be regularly incorporated into the assessment of cumulative radiation exposure of occupationally exposed persons in the DICOM RDSR format [1, 50-55], precisely on the basis of the resolved integration of the X-ray device and protective screen, and relevant radiation exposure assessment (whose primary goal is to estimate the reference positioning of the screen) that can be obtained in this way.

CONCLUSIONS

The presented solution can be applied to all existing C-arm X-ray devices and on newly manufactured ones, in order to improve radiation protection and for more explicit estimation of personnel exposure during interventional procedures.



(a) (b) (c)

Figure 2. Example of screen repositioning in case the X-ray tube-detector system moves to the caudo-cranial position: (a) the initial position of the screen, (b) the state of the screen position, after rotation by the corresponding angle laterally, in the clockwise/counterclockwise direction, and (c) condition after curving the screen around the *x*-axis, by the appropriate angle, with the upper edge forward/lower edge forward

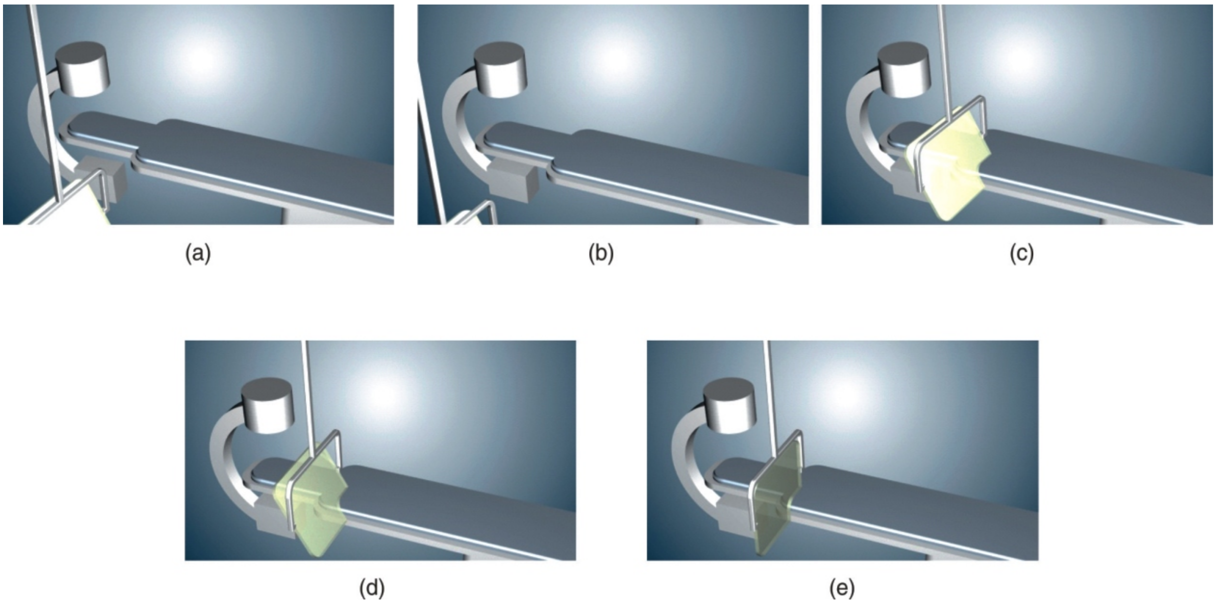


Figure 3. Example of screen management if it needs to be changed for the patient table position, during the intervention: (a) as soon as the patient table movement initialization starts it is necessary that the screen should be automatically unlocked, considering potential collisions (and manually moved to a safe position) , (b) the patient table (in this example) descends to the desired height, (c) the screen should be set manually again and, after that, automatic repositioning should be initiated, (d) the state of the screen position after rotation by the corresponding angle laterally in the, clockwise/counterclockwise direction, and (e) condition after screen rotating by the appropriate angle, with the upper edge forward/lower edge forward (and, subsequently, screen lock in the newly established state)

Staff will be unrestrained performing medical activities, knowing that the protective screen will be positioned and repositioned during the procedure, to provide the best possible protection.

The overall result will surely have a massive influence on the fundamental research development in radiation protection and dosimetry, and, consequently, will lead to related products and advancements.

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ПОЛУАУТОМАТСКИ ПОСТУПАК ПОЗИЦИОНИРАЊА ЗАШТИТНОГ ЕКРАНА НА БАЗИ ИНТЕГРАЦИЈЕ СА РЕНДГЕН УРЕЂАЈЕМ СА *C*-ЛУКОМ

При флуороскопски праћеним интервентним процедурама, висећи екран се користи за заштиту особља од расејаног зрачења од пацијената. Правилно позиционирање екрана је кључно за адекватну заштиту од јонизујућих зрачења професионално изложених лица. Предложено решење у овом раду обезбеђује поуздану и ефикасну заштиту од расејаног зрачења, на бази интеграције рендген уређаја и висећег екрана у један систем преко одговарајућег интерфејса. Након иницијалног мануелног позиционирања, изврши се аутоматско репозиционирање екрана, закривљењем латерално, у смеру или супротно смеру сказаљке на сату, па онда горњом или доњом ивицом напред. Све потенцијалне клиничке ситуације су анализиране, са обзиром на потребу за корекцијом позиције екрана: полуаутоматски начин је осмишљен и реализован да прати медицинску процедуру са циљем да задржи ефикасан ниво заштите особља од јонизууђих зрачења. Осим тога, процена радијационе дозе за особље, обезбеђена преко оптимизације позиције екрана, ће се укључити у структурални извештај о радијационој дози. Применом универзалног интерфејса, презентовано решење се може применити не само на новопроизведеним већ такође и на постојећим рендген уређајима са *C*-луком.

Кључне речи: заштитни екран, рендген уређај, интерграција, полуаутоматско позиционирање, процена дозе за професионално изложена лица