

Using Fuzzy Inference System to Develop an Optimal Tube Voltage and Tube Current Chart for Radiation Reduction in Pediatric CT Examinations

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Abstract— Many different techniques and researches on reducing the radiation dose for computed tomography (CT) examinations have been reported and developed in recent 30 years. However, most those technologies are not practical enough to enable them to be directly and easily implemented in clinic real applications because there is no directly relationship between those techniques and the actual CT scanning parameters to be applied on most clinic pediatric CT examinations. In this study, a practical and flexible technique chart is developed to enable radiologists to select the optimal tube voltage and tube current for the given body-size of the pediatric patients with the desired CT dose index ($CTDI_{vol}$). This chart can be easily implemented in most clinics for routine pediatric CT examinations.

Keywords-fuzzy inference system; reduction of radiation dose; pediatric CT examinations; optimal tube voltage; optimal tube current

I. INTRODUCTION

In last three decades or so many technologies have taken a quantum leap and methods have been developed and reported to reduce the radiation dose during the use of computed tomography (CT) scan in pediatric patients [1-18]. One of the most important reasons for these developments is the potential risk of cancer that results from the radiation used in CT scans [19-21].

Different technologies have been reported to reduce the radiation dose, such as reducing the tube current and tube voltage [7, 11, 15], shortening the scanning times ,adoption of automatic tube current modulation method [22-25] and using the different scanning protocols in addition to selecting the optimal tube voltage and tube current [26-27].

The use of a lower tube potential to reduce radiation dose in pediatric patients has been actively reported and investigated [2-4, 8, 14, 26-27]. Most CT examinations involve the use of iodinated contrast material.

However, most of these technologies and developments do not translate into real life clinical applications because they lack a direct relationship or mapping between these

techniques and the actual CT scanning parameters applied on most of the pediatric CT examinations. One potentially good technique that can be adopted by the clinics is to build a flexible chart for tube potential and tube current settings for pediatric body CT examinations. Lifeng Yu et al. reported a method to implement a technique chart for tube potential and tube current settings for pediatric body CT examinations [27]. They also discussed special considerations and common pitfalls associated with the use of lower tube potentials for pediatric imaging. However, the developed optimal parameters, such as optimal tube voltages and tube currents, are limited to some special body-sizes of pediatric patients. In this paper, we developed and build a more flexible technique chart of the optimal tube potential and tube current settings for pediatric body CT examinations based on the chart reported by [27]. This chart enables the radiologists to select the optimal tube voltage and tube current settings based on real body-size of any pediatric patient and desired CT Dose Index ($CTDI_{vol}$) in real time that can be easily implemented in most of the routine pediatric CT examinations.

The factors that affect the reduction of the radiation dose, such as the patient size-dependent beam-shaping filter, automatic exposure control (AEC), image noises, scanning speed and contrast-to-noise ratio (CNR), will not be discussed in this paper as they have already been discussed in detail in [27]. We will directly use the weight-based chart that established a noise-matched technique at a lower tube potential as reported by [27], to build our own flexible technique chart. All associated tube current values used in this paper have been converted to the noise-matched tube current values using the method developed in [27]. The scanning time is 0.33 seconds.

The advantage of using our flexible technique chart is that the radiologists can select the desired $CTDI_{vol}$ based on the actual given body-size of the pediatric patient to be examined (inputs). They can also obtain the optimal tube voltage and tube current settings (outputs) from this chart

directly and easily. This kind of chart will be more suitable and appropriate for clinical examinations and diagnoses.

II. MATERIALS AND METHODS

We used the fuzzy inference system (FIS) to build a technique chart to set a mapping relationship between each body-size and weight and the desired optimal tube voltage and tube current based on the desired $CTDI_{vol}$. All related data and operational parameters used for this chart are based on those provided by [27]. Two optimal technique charts developed by [27] are shown in Tables 1 and 2. Table 1 is for routine pediatric chest CT examinations, and Table 2 is for routine pediatric abdominopelvic CT examinations.

TABLE I. WEIGHT-BASED TECH CHART FOR TUBE POTENTIAL AND TUBE CURRENT FOR ROUTINE PEDIATRIC CHEST CT EXAMINATIONS

Weight (kg)	Tube Potential (kV)	QRM*	AEC†	Pitch	Rotation Time (sec)	Kernel	Section/Interval Thickness (mm)	Collimation (mm)	$CTDI_{vol}$ (mGy)‡
<10	80	150	On	1.2	0.33	B40f	3/3	64 × 0.6	2.1 ± 0.2
10–20	100	70	On	1.4	0.33	B40f	3/3	64 × 0.6	3.5 ± 0.3
20–45	120	40	On	1.4	0.33	B40f	3/3	64 × 0.6	5.2 ± 1.2

TABLE II. WEIGHT-BASED TECH CHART FOR TUBE POTENTIAL AND TUBE CURRENT FOR ROUTINE PEDIATRIC ABDOMINOPELVIC CT EXAMINATIONS

Weight (kg)	Tube Potential (kV)	QRM*	AEC†	Pitch	Rotation Time (sec)	Kernel	Section/Interval Thickness (mm)	Collimation (mm)	$CTDI_{vol}$ (mGy)‡
<10	80	190	On	1.1	0.33	B40f	3/3	64 × 0.6	2.2 ± 0.3
10–20	100	90	On	1.4	0.33	B40f	3/3	64 × 0.6	3.8 ± 0.4
20–45	120	50	On	1.4	0.33	B40f	3/3	64 × 0.6	5.1 ± 0.7

It can be seen from both the tables above that these technique charts only provide relationships or mappings between the body-size and the optimal tube voltage and tube current for three set ranges of body-size viz. 0 ~ 10 kg, 10 ~ 20 kg and 20 ~ 45 kg. In other words, these charts are not complete or continuous because they do not provide all optimal tube voltages and tube currents for each different body-size. These charts can be termed as ‘discrete’ charts.

In this study, we will use the fuzzy inference system (FIS) to build complete and continuous technique charts to provide all related optimal tube voltages and tube currents for each different given body-size in real time. In fact, we will use FIS to interpolate the optimal tube voltage and tube current for each specified body-size based on the given charts developed by [27].

To make our study simple, we only used Table 1, for routine pediatric chest CT examinations, as an example to illustrate how to build this flexible and complete technique chart. A graphic representation of Table 1 is shown in Fig. 1.

The basic idea behind this development is based on the fact, that the optimal tube potential and tube current are not continuous functions for all different body-sizes located between known body-sizes. Also the relationship between the optimal tube voltage and tube current and different body size is ambiguous, at least it is not a linear one as shown in

Figure 1. Therefore we need to use the fuzzy inference algorithm to derive those optimal tube voltages and tube currents for all those ‘missed’ body sizes. In fact, we use fuzzy inference method to interpolate those optimal tube voltages and tube currents for any specified body-size.

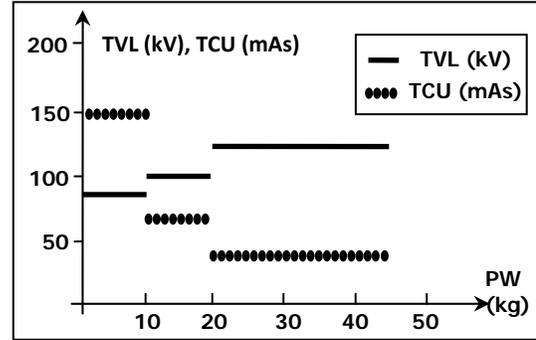


Figure 1. Graphic representation of Table I - Pediatric chest CT exam.

III. FUZZY INFERENCE SYSTEM

We use desired $CTDI_{vol}$ and given actual body-size of the pediatric patient to be examined as inputs, and the optimal tube voltage and tube current as outputs for a fuzzy inference system. Therefore this is a multi-input and multi-output system. Both inputs and outputs are connected and controlled by the control rules.

Fig. 2 shows the block diagram of this fuzzy inference system.

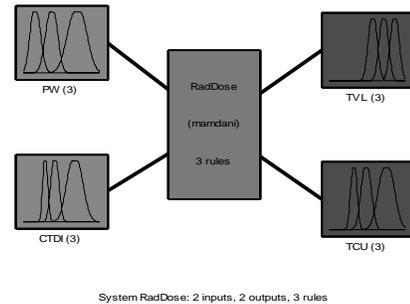


Figure 2. The block diagram of the fuzzy inference system.

As for the membership functions for two inputs, $CTDI_{vol}$ and patient weight, we utilized *gauss2form* as the shape for both of them. Similarly, this shape is also used for two outputs, the optimal tube voltage and tube current.

The membership functions for both inputs are shown in Fig. 3. The membership functions for both outputs are shown in Fig. 4, respectively. Those membership functions are derived based on the data provided by [27] for routine pediatric chest CT examinations.

For this implementation, three control rules are developed based on the input-output conditions listed in [27]. These three control rules are shown in Table 3. The

surface of TVL over PW and CTDI is shown in Fig. 5, and the surface of TCU over PW and CTDI is shown in Fig. 6.

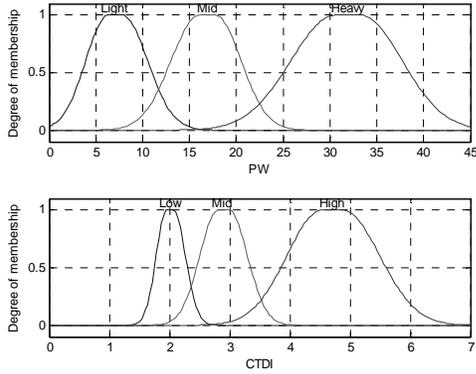


Figure 3. Membership functions - inputs, patient weight (PW) and CTDI.

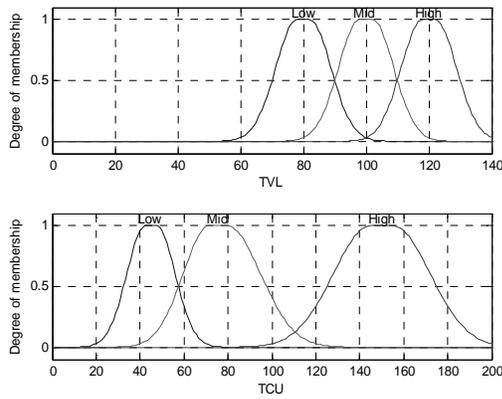


Figure 4. Membership functions - outputs, tube voltage and tube current.

TABLE III. THREE CONTROL RULES

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|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <ol style="list-style-type: none"> 1. If (PW is Heavy) and (CTDI is High) then (TVL is High) & (TCU is Low) (1) 2. If (PW is Mid) and (CTDI is Mid) then (TVL is Mid) & (TCU is Mid) (1) 3. If (PW is Light) and (CTDI is Low) then (TVL is Low) & (TCU is High) (1) |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

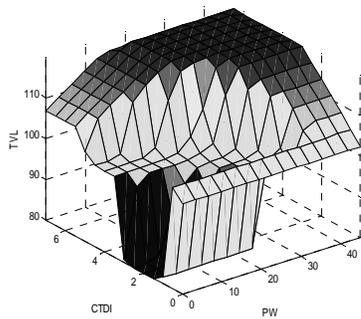


Figure 5. Tube voltage (TVL) over PW and CTDI.

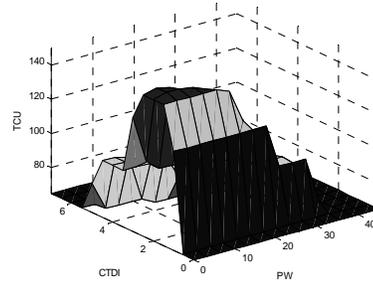


Figure 6. Tube current (TCU) over PW and CTDI.

IV. IMPLEMENTATION RESULTS

Based on the membership functions of two inputs, Patient Weight (PW) and CT Dose Index ($CTDI_{vol}$), and membership functions of two outputs, tube voltage (TVL) and tube current (TCU), discussed in the last section, the flexible technique chart for optimal tube voltage and tube current for the given body-size and desired $CTDI_{vol}$ can be easily built and developed. Fig. 7 shows this kind of chart used for routine pediatric chest CT examinations.

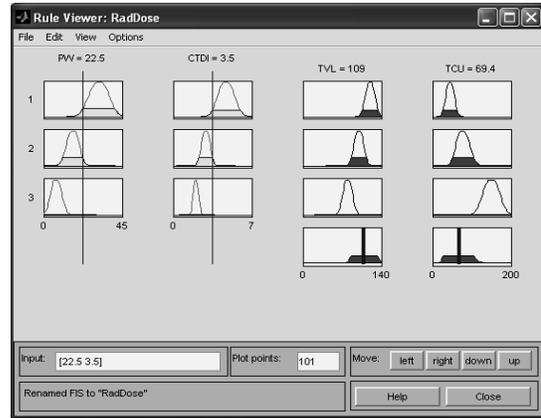


Figure 7. Technique chart for pediatric chest CT examinations.

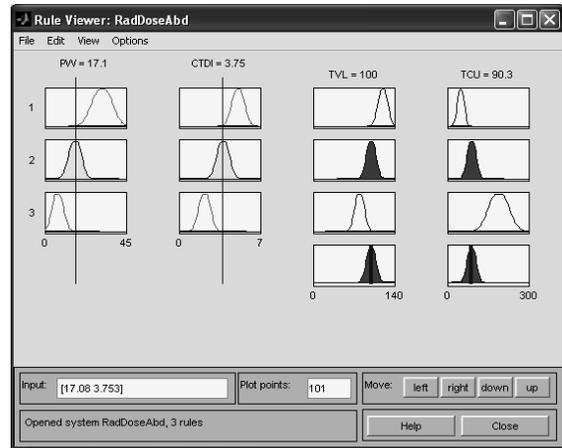


Figure 8. Technique chart for pediatric abdominopelvic CT examinations.

In Fig. 7, a typical body-size (22.5 kg) and $CTDI_{vol}$ (3.5) are selected. The related optimal tube voltage and tube current are 109 kV and 69.4 mAs, respectively.

During the implementation process, the vertical bars on the PW and the $CTDI_{vol}$ in this chart can be moved by the user to either left or right to select the specified body-size and desired $CTDI_{vol}$ based on their actual situations. The optimal tube voltage and tube current can be obtained immediately when the selected input parameters, such as the body-size and desired $CTDI_{vol}$, are determined by the users. We can also build a similar technique chart using the data provided by [27] for the pediatric abdominopelvic CT examinations using the FIS, which is shown in Fig. 8.

V. CONCLUSION AND DISCUSSION

A flexible technique chart used to set direct relationship between selected body-size with desired $CTDI_{vol}$ and the optimal tube voltage and tube current is developed in this paper to enable radiologists to easily and practically select the optimal scanning parameters for routine pediatric chest and abdominopelvic CT examinations in clinics. The advantage of using this chart is that the radiologists can select the desired $CTDI_{vol}$ based on the actual given body-size of the pediatric patient to be examined to obtain the optimal tube voltage and tube current settings from this chart directly and easily.

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