DYNAMIC BEAM ATTENUATOR

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ABSTRACT

Traditional X-Ray computed tomography employs a point-source X-Ray generator that projects uniform radiation in a fan-shaped array through the patient which after the data processing results in a two dimensional image. When this process is repeated at different planes around the axis of revolution of the subject a three dimensional image can be produced. This procedure is suboptimal, however, due to the heterogeneous nature of patients which results in superfluous noise and patient exposure to radiation. Methods have been attempted to attenuate the X-Ray beams in order to remedy these issues, such as a static bowtie filter that reduces radiation as you travel distally in the coronal plane or X-Ray tube modulation which alters the current being delivered to the source, resulting in a temporal change in energy emitted. Nevertheless, neither of these methods allows for real time dynamic attenuation, in which the X-Rays are altered in both space and time. As such, our client suggested we develop a prototype consisting of attenuating wedges that can be actuated into and out of the X-Ray field, altering the amount of radiation delivered to the patient at that point in space and time. A series of these wedges aligned in parallel would allow for different attenuation across the patient, ultimately decreasing noise and overall radiation exposure to the patient.

In order to investigate which material would be best suited to be machined into wedges, simulations were first run in Matlab to determine the thickness of each element required to attenuate X-Rays to the same degree as 36 cm of soft tissue and 1 cm of bone, representing the most our design would have to attenuate. From these results, five suitable materials were chosen and their individual beam hardening effects were analyzed and Tungsten was chosen as the optimal material. Linear actuators and a rack and pinion system were investigated in order to actuate the wedges, and due to scalability and important space constraint a rack and pinion method of actuation was chosen. A preliminary design was determined utilizing a minimally attenuating material as the rack with the rotary servo motors placed outside the active X-Ray area. The racks may be staggered in length to allow for larger motors to be installed. Future work includes fabrication of the wedges, finalization of specific actuation parts, constructing a housing for the prototype, testing the device using phantoms, and performing final modifications based on client input and test results.

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INTRODUCTION

CLIENT DESCRIPTIONS

Dr. Charles Mistretta is a Professor of Medical Physics and Radiology for the University of Wisconsin School of Medicine and Public Health [1]. His group was responsible for the development of digital subtraction angiography (DSA) and his current research interests include the development of 4-dimensional DSA technology and dynamic beam attenuation (DBA) in X-Ray computed tomography (CT) scanning [2]. Dr. Mistretta is also an Affiliate Professor in the Biomedical Engineering department and holds a research partnership with the University of Wisconsin Biomedical Engineering Center for Translational Research [3]. He has published work in numerous peer-reviewed journals and has generated 33 US patents [4].

Timothy Szczykutowicz is a doctoral degree student in the Department of Medical Physics at the University of Wisconsin-Madison. He is working on the dynamic beam attenuator project under Dr. Mistretta. Some of his current work pertains to calculating the level of attenuation required to produce quality, clear images and to determining how to reconstruct the image after attenuation has dynamically altered the intensity of X-Ray photons. Siemens, a global electrical engineering company, is funding the DBA project and has also provided an Artis Zeego Multi-Axis C-Arm CT scanner to use in DBA research [5]. Siemens hopes to integrate DBA into next generation CT scanners to improve image quality and lessen the adverse effects of radiation exposure.

Our clients have proposed that we design and actuate a wedge-based X-Ray attenuating prototype to be used during DBA research.

X-RAY COMPUTED TOMOGRAPHY

Until the later part of the 20th century, the primary method of imaging in medical diagnostics was X-Ray radiography. This method projects X-Rays from a generator that pass through the desired object (in medical circumstances, the patient), and are detected by a sensor opposite the source [6]. The variation in density and composition of the patient would correspond to the black and white contrast in the final X-Ray image [7].

In 1979, the Nobel Prize in Physiology for Medicine was awarded to Allan M. Cormack and Godfrey N. Hounsfield for their “development of the computer assisted tomography” [8]. The limitation that traditional X-Ray imaging posed was its inability to produce three-dimensional images. With the advent of X-Ray computed tomography, three-dimensional images could be produced—a breakthrough that would greatly improve diagnostic radiology [9].

Figure 2: A conventional CT machine developed by General Electronics Healthcare [10].

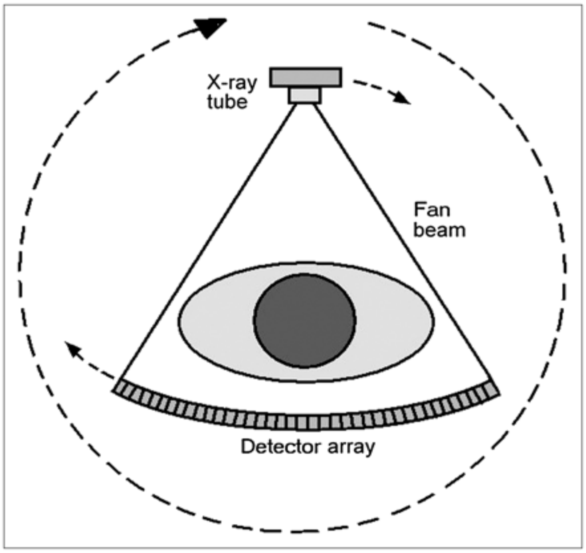


Figure 2: Schematic of a point-source-generated fan shaped X-Ray beam with a patient positioned between the beam source and the detector. No beam attenuation exists in this model [11].

The X-Ray CT employs a point-source X-Ray generator that projects X-Rays in a fan-shaped array through the patient. Figure 1 shows a conventional CT machine; the patient is inserted into the round opening and the scanning procedure commences. The X-Rays are detected by a detector on the opposing side [12]. A schematic of the relative positions of the patient, the X-Ray beam generator, and the X-Ray detector is shown in Figure 2. The number of X-Rays that pass through the patient are detected and used to construct planar images. This method is repeated at multiple planes around the axis of revolution of the subject being scanned in order to produce image “slices”. These slices are then compiled to produce a three-dimensional image, allowing what would traditionally be generated as pixels in a two-dimensional scan to be generated as three-dimensional voxels [13]. These three-dimensional reconstructions are then used by a variety of medical personnel for diagnoses. The benefits of this type of imaging include the ability to perform procedures with real time visual streaming and the non-invasiveness of the overall procedure. The method, however, also carries the disadvantage of increased lifetime cancer risk for the patient due to exposure to high intensity X-Ray beams [14]. In addition, there are certain qualitative drawbacks to the current method of computed tomography; the most notable being low image quality caused by the lack of beam attenuation.

CURRENT METHODS

One current shortcoming of X-Ray computed tomography is the use of a uniform incident beam despite the fact that the transmission through the patient varies significantly due to differences in tissue densities within the patient [15]. This results in a number of different problems. One problem is that a low, non-uniform signal-to-noise ratio can be a result of a non-attenuated, uniform beam; if the signal-to-noise ratio is too low or is non-uniform, a grainy and substandard image is produced. Also, because the beam is of a constant intensity, a sub-optimal distribution of X-Ray scatter occurs. If the beam were to be continually attenuated to account for the density and composition of the subject, fewer X-Rays would scatter, consequently resulting in a clearer final image [16]. Finally, significantly higher doses than necessary are administered to some regions and insufficient doses are administered to others [17].

X-Ray beam attenuation is one of the methods currently used to address these problems. X-Ray beam attenuation is defined as a reduction in X-Ray intensity; this reduction occurs after the X-Rays have been generated. One way to attenuate X-Ray beams is by using X-Ray tube modulation [18]. Concern about the amount of X-Ray exposure due to the high intensity beams necessary for diagnostic resolution led to the development of modulation of the X-Ray tube. This modulation is achieved by controlling the current in the X-Ray tube based on the necessary X-Ray beam intensity. The beams are either modulated based on preprogrammed predictive algorithms, or on continuous real-time feedback adjustments [19]. This is the primary method of accounting for the high dosage of X-Rays that patients are exposed to without compromising the quality of the final images [20].

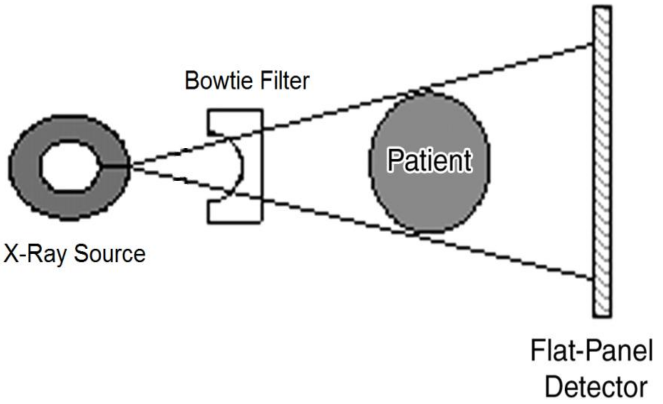


Figure 3: Schematic of a point-source-generated fan shaped X-Ray beam with a bowtie filter positioned between the beam source and the patient. Passive beam attenuation exists in this model [21].

Static filters, such as the bowtie filter shown in Figure 3, are also used in point-source-generated fan shaped X-Ray beam CT machines. This 'bowtie-shaped' component attenuates the X-Ray beams to a greater degree nearer to the outer edges of the X-Ray fan and less at the center of the bowtie, which corresponds to the areas of the patient with the greatest thicknesses. This filtration is designed to attenuate X-Rays based on the average shape in the human form and, besides X-Ray tube modulation, is one of the few methods of reducing X-Ray dosage during a CT scan.

DESIGN OVERVIEW

The goal of this device is to regulate the amount of X-Rays that each region of the patient receives at any given time. Our clients have proposed to do this using a series of paired wedges. By changing the amount of overlap and consequently the path length the beam must travel through, the amount of attenuation can be controlled throughout the duration of the scan. When the wedges are maximally overlapped, as seen in Figure 4, the X-Rays have to pass through a greater path length, which lowers the dosage delivered to the patient. However, if one wedge is slid away, as in Figure 5, the total thickness decreases and thus allows more X-Rays to pass. A series of wedge pairs placed between the X-Ray source and the patient could then adjust the total radiation passed to each region of a patient throughout the duration of a scan.

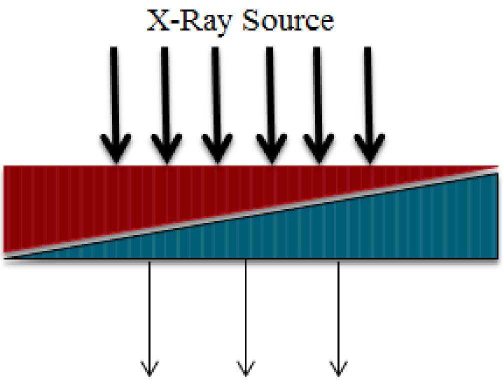


Figure 4: Overlapped wedges create high attenuation, allowing few X-Rays to pass through to the patient.

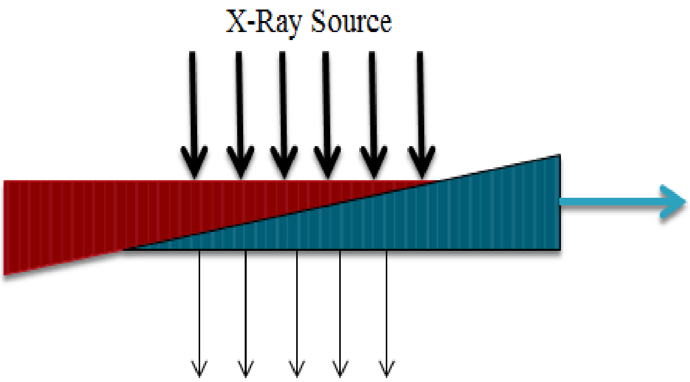


Figure 4: By sliding one wedge away, the amount of overlap decreases. This causes less attenuation and allows more X-Rays to pass.

CURRENT PROTOTYPE

The current prototype, as seen in Figure 6, consists of a fixed top wedge-shaped plate and ten individual hand-actuated wedges. It was manufactured out of steel and is extremely heavy. In addition, this design has arbitrary wedge thicknesses and dimensions, so it cannot optimally attenuate X-Ray beams to meet the needs of our client. The current prototype uses a 56.4 mm wide motor to actuate a single 17.5 mm wedge; this setup is not ideal as it does not allow easy actuation of small-width wedges without significant modification. We seek to create a prototype that would be to scale with the CT X-Ray source housing and cover the field of view used during a clinical scan. We also seek to individually actuate all wedges.

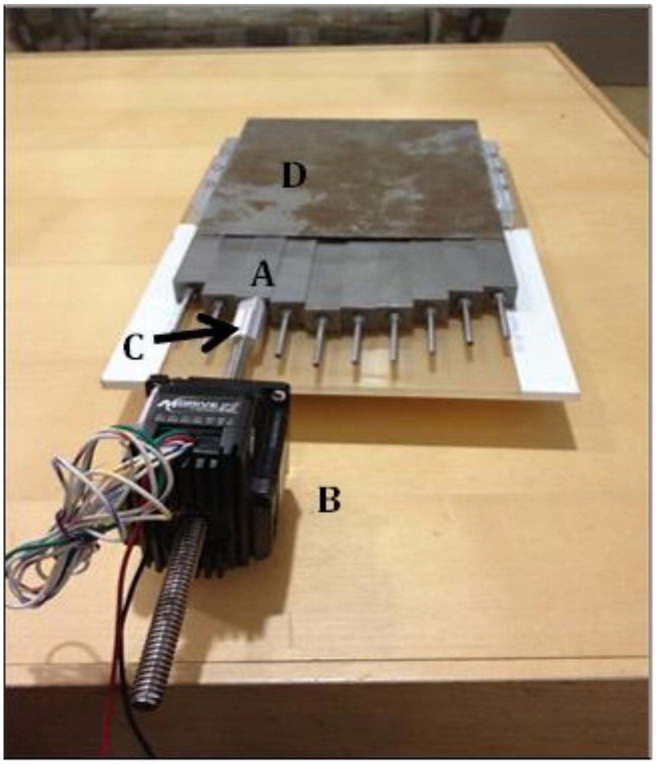


Figure 5: Actuated Prototype. The motor (B) drives the actuated wedge (A) inside the prototype housing (D) with a stroke length of up to 10 cm. The wedge is connected to the motor via an adaptor (C).

DESIGN CRITERIA

The design must be accurate, compact, and resistant to X-Ray radiation. It cannot interfere with any part of the procedure or compromise the safety of the technician or the patient in any way.

Firstly, the device needs to alter the strength of the X-Ray beam as a function of position for the duration of the Computed Tomography (CT) scan. In order to accomplish this, the actuator chosen must actuate the wedges to satisfy a minimum distance that encompasses approximately half of the area of the detector. The actuator must also move the wedges with an accuracy of 1mm.

All components of the design shall be small enough to fit within the housing of the CT machine, which is approximately 27.94 centimeters. This is to demonstrate to Siemens, as a proof of concept, that this device could be constructed to scale to fit within the machine.

In addition, all parts should be resistant to damage by X-Ray radiation. The wedge material must be homogeneous in order to uniformly transmit X-Rays and correctly attenuate the X-Ray beams. The wedges should also slide with a low coefficient of friction. If implemented clinically, the device must have a life in service equal to that of the CT scanner.

Lastly, the device should be safe and comfortable for both the medical personnel and the patient. No component should interfere with the execution of the procedure. The budget given by the client is approximately $5000.

MATERIALS

In order to determine which material to pick for the final design, a few criteria were considered, including material thickness and beam hardening. Beam hardening is the uneven change in the X-Ray energy as it passes through a material, so that X-Rays with lower energies attenuate more than those with higher energies, which causes artifacts during CT image reconstruction. MATLAB was used to calculate the minimum material thickness required to attenuate the X-Rays to the same level as 36 cm of soft tissue and 1 cm of bone. These values were chosen to model the chest and lung area, due to the large variation of ideal X-Ray dosages required between the sternum and the lungs. Equation 1 was used to match the amount of leaf material seen by the detector to the amount of patient material, where R is the specified thickness of soft tissue and bone, $\Omega(\mathrm{E})_k$ is the signal detected for a given spectrum at peak potential k, $w(E)$ is the detector energy, μ is the linear attenuation coefficients, and t_{tissue} and t_{bone} are soft tissue and bone thicknesses, respectively. In order to calculate the leaf thickness required, Equation 2 was used, and subsequently implemented into MATLAB (MATLAB code can be found in Appendix A.)

$$R_{t_{tissue},t_{bone}} = \int dE\Omega(E)_k \cdot w(E) \cdot \exp(-t_{tissue} \cdot \mu(E)_{tissue} - t_{bone} \cdot \mu(E)_{bone}) \qquad (1)$$

$$f(t_{leaf}) = \left| R_{t_{tissue},t_{bone}} - \int dE \cdot \Omega(E)_k \cdot w(E) \cdot \exp(-t_{leaf} \cdot \mu(E)_{leaf}) \right| \qquad (2)$$

Using these relationships, required left thicknesses for elements with atomic numbers 1 to 92 at 100 kVp were calculated; the results are shown in Figure 7. The energy specific attenuation values and mass densities for each material were obtained from NIST databases [22].

In Figure 7, one can clearly see the wide range of thicknesses required for each element. The peaks correspond to noble gases; a significant amount of gas is required to attenuate 36 cm of soft tissue and 1 cm of bone. The smallest leaf thickness is ideal, but other limitations, such as material availability and machinability, must also be considered.

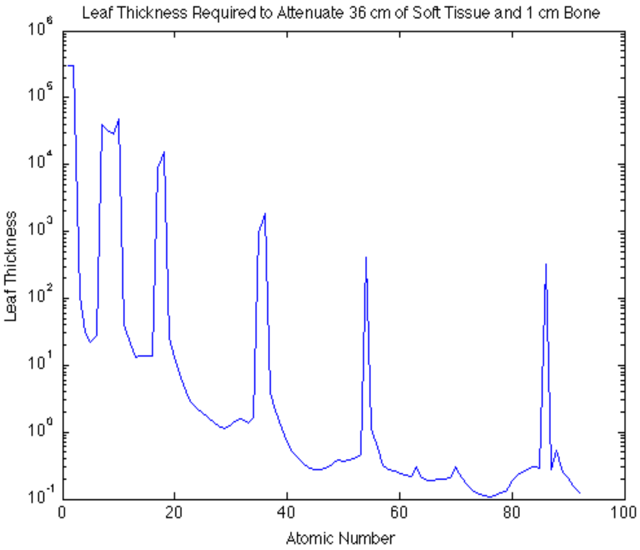


Figure 7: Leaf thickness required for elements with atomic number 1-92 to attenuate the same degree as 36 cm of soft tissue and 1cm of bone.

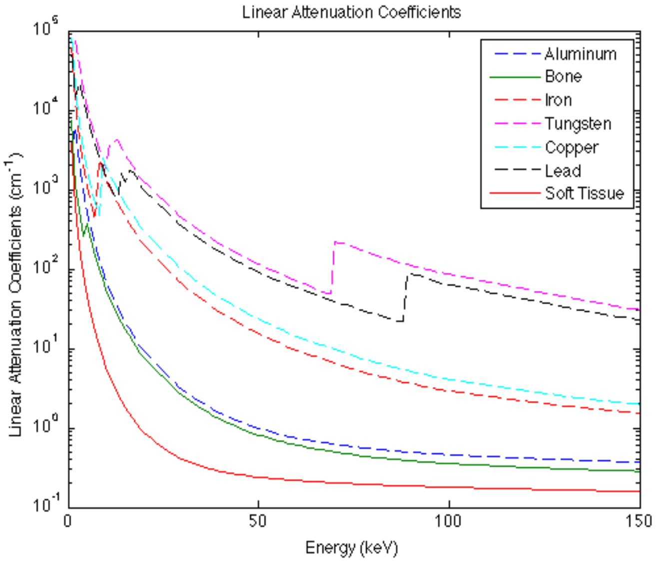


Figure 7: Linear attenuation coefficients as a function of energy for a variety of materials.

By using these calculations, several materials were identified as potential wedge materials, including tungsten and copper. Research on materials currently used in radiation shielding and X-Ray technology revealed that lead, iron, and aluminum were also feasible materials to consider. These materials were then further analyzed by plotting the linear attenuation coefficients as a function of energy (Figure 8).

An ideal linear attenuation coefficient would be horizontal in this figure, or in other words, constant with respect to energy. However, as attenuation is a function of X-Ray photon energy, constantly attenuating materials do not exist. As a result, materials that have the lowest deviation from a constant mean energy are preferred. The data in Figure 8 show that tungsten and lead are the two materials that have the lowest deviation. All materials have k-edges, the jumps in linear attenuation coefficients at a characteristic X-Ray photon energy, but typically at much lower energies (less than 20 keV). A more constant mean energy within the middle of the diagnostic imaging X-Ray spectrum, 50 keV-100 keV, reduces beam hardening and therefore improves image quality.

To visually model the large differences in leaf thickness for the five materials considered, SolidWorks files of each material were created, and are shown in Figure 9. All dimensions were constant except for the heel thickness. Aluminum was scaled differently to improve comparability between heel thicknesses. These heel thicknesses were calculated by determining the amount of material required to match the signal produced by 36 cm of soft tissue and 1 cm of bone and range from 129.7 mm (Aluminum) to 1.2 mm (Tungsten).

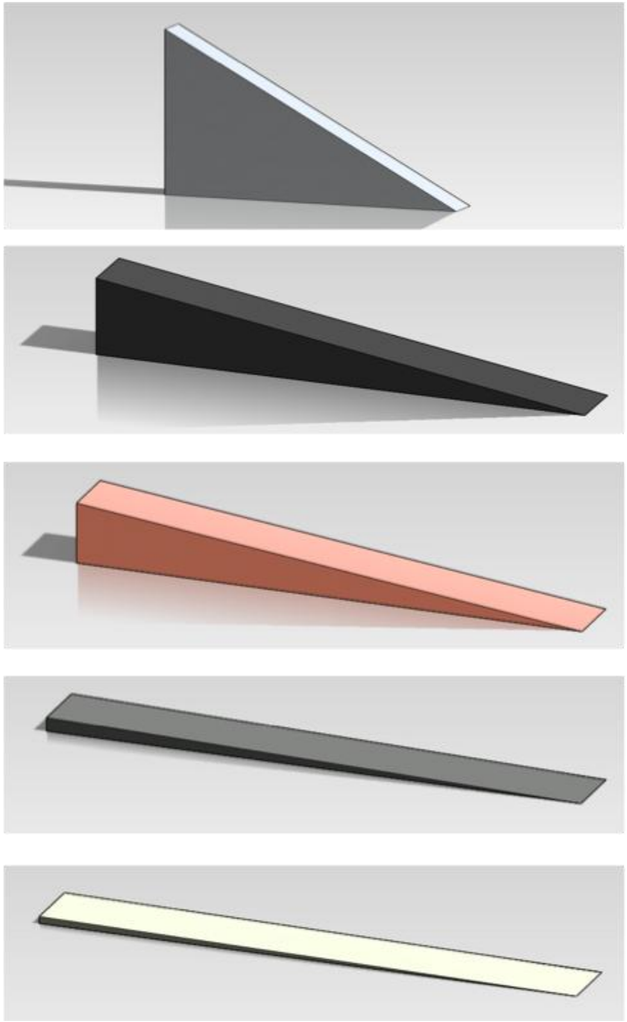
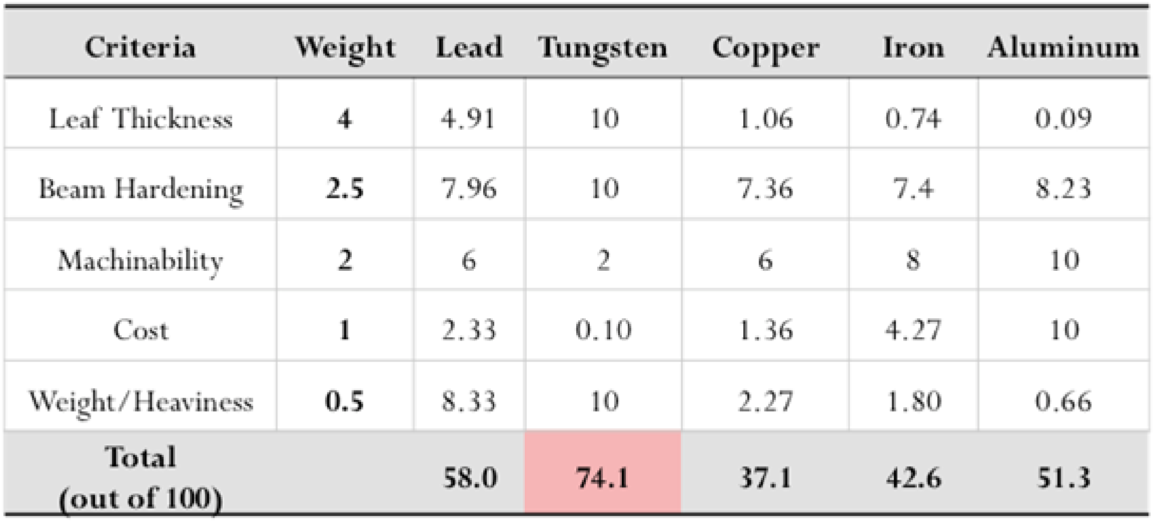


Figure 9: Leaf thicknesses for aluminum, iron, copper, lead, and tungsten, from top to bottom. Heal thicknesses were 129.7 mm, 16.3 mm, 11.4 mm, 2.5 mm, and 1.2 mm, respectively.

After considering these simulations, a design matrix was constructed for five criteria: leaf thickness, beam hardening, machinability, cost, and heaviness (shown in Table 1). The values for each category were quantitatively determined from calculations and then normalized to a scale of 1 to 10, with the best material receiving a 10. Each criterion was then weighted according to importance so that the grand total was from 1 to 100. Both leaf thickness and beam hardening were calculated using the MATLAB simulations discussed earlier, and were

Table 1: Materials design matrix. Values were quantitatively determined and normalized to a scale from 1 to 10. Each criterion was then weighted so that the grand total was from 1 to 100.



Criteria	Weight	Lead	Tungsten	Copper	Iron	Aluminum
Leaf Thickness	**4**	4.91	10	1.06	0.74	0.09
Beam Hardening	**2.5**	7.96	10	7.36	7.4	8.23
Machinability	**2**	6	2	6	8	10
Cost	**1**	2.33	0.10	1.36	4.27	10
Weight/Heaviness	**0.5**	8.33	10	2.27	1.80	0.66
Total (out of 100)		**58.0**	**74.1**	**37.1**	**42.6**	**51.3**

given the largest weight because these two criteria are necessary for the proof of concept to work. Tungsten received the highest score in both these categories, because it had the smallest leaf thickness and the smallest beam hardening artifact. Machinability was considered next in importance. These values were determined based on rankings by a professional machinist, given the dimensions and leaf thicknesses required for each material. Aluminum was deemed easiest to machine, and tungsten the most difficult. The lowest criteria were cost and heaviness, due to our relatively high budget and the consideration that the final design is only a proof of concept and will be stationary. However, it is important to note that heaviness will be a significant criterion to consider when implemented into the C-arm CT scanner since the C-arm will be rotating 270 degrees and a heavy design would cause balance problems. With these criteria, tungsten received the highest score, and will be the material used in the final design.

METHODS OF ACUTATION

After consulting with Erick Oberstar of the Mechanical Engineering department at the University of Wisconsin-Madison, two main methods of wedge actuation were considered to properly actuate the attenuating wedges [23]. The first method is a linear DC-Servomotor, which has the attractive feature of containing a position and speed feedback mechanism incorporated into the motor. This feature allows the motor to automatically correct for errors between the control signal and physical output. The best choice for this type of motor was determined to be the Series LM 1247 Linear DC-Servomotor with Analog Hall Sensors QUICKSHAFT Technology due to its stroke length, continuous force, precision, and size [24]. A Solidworks representation of a linear DC-Servomotor attached to an attenuating wedge is depicted in Figure 10. These motors present a problem, however, when considering the scalability and size constraints of the design. The Artis Zeego Multi-Axis C-Arm CT scanner's source enclosure, within which our prototype is designed to fit, has only a 25.4 square centimeter space to work within. If the linear servomotors were implemented, the motors themselves would require more space than the attenuating wedges. To account for the increased space requirement, the wedge length must decrease. If

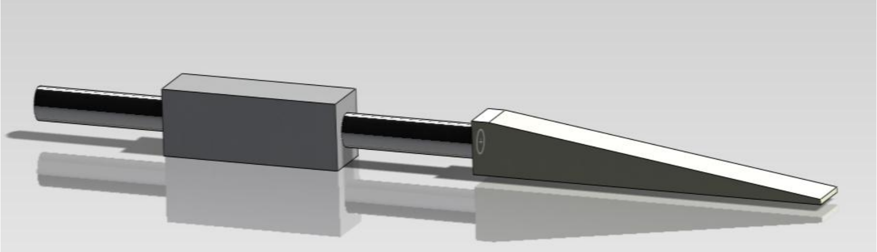


Figure 10: Solidworks representation of a linear DC-Servomotor attached to attenuating wedge.

the length of the wedge were decreased while maintaining the heel height, an increase in the error would arise due to a steeper wedge angle. Else, the wedge length and heel height could be decreased, but this would diminish the dynamic range of attenuation. Both of these outcomes are undesirable, so another form of actuation was considered.

The second possible method of actuation involves a rack and pinion system. The rack, or linear "gear" bar, would be affixed to the underside of the metal wedge, and be comprised of a minimally attenuating material such as plastic, nylon, or aluminum (Figure 11). The rack would create a baseline attenuation, but that value is easily accounted for during image reconstruction. The non-uniform surface due to gear pockets would also not cause a problem due to the "bucking grids" which are shaped like Venetian blinds and only allow radiation to be passed through to the detector that originated form the source, thus filtering out scattered beams [25]. The pinion, or circular gear, would be affixed to a brushless DC Servomotor, again provided by Micromo. Since these motors are also available with optional digital or analog hall sensors for position and velocity feedback, precision and position control are maintained. This design also allows for variable gear ratios to allow fine tuning of torque and speed with any given motor. The most attractive feature that differentiates this method of actuation from the linear motors is its compressed size. With a rack and pinion system, the majority of the area of the device can be utilized by the wedges, which maximizes dynamic attenuation range while minimizing error. For these reasons, the rack and pinion method of actuation should be utilized in the preliminary design.

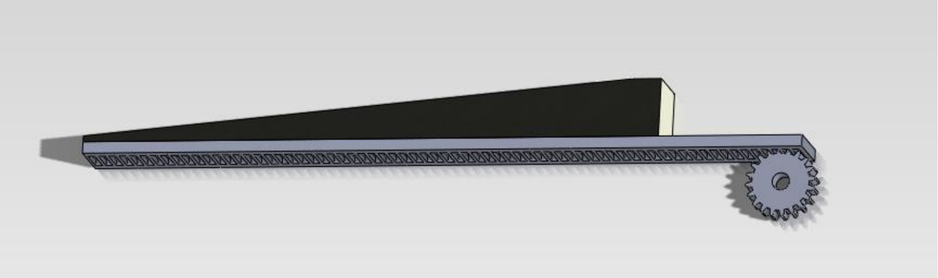


Figure 11: Solidworks representation of rack and pinion system attached to attenuating wedge.

PRELIMINARY DESIGN

The preliminary design consists of seven actuating wedges and seven stationary wedges. The stationary wedges would also be replaced by a single solid plate as seen in the current prototype. The reason this design is simply preliminary, as opposed to final, is that the team is currently negotiating with manufacturing companies for quotes on different wedge designs which will ultimately determine the final motor requirements such as peak and continuous force, likely altering the final design. However, by using spatial constraints to determine the actuation method, we created the preliminary design seen in Figure 12. Ideally, tungsten wedges based off the previously discussed design matrix will be used in this design. These wedges have a required heel thickness of only 1.2 mm, which means an additional material must be adhered to the wedge to allow attachment to any motor. This requirement supports the decision to choose the rack and pinion method because the rack can simply be attached along the surface of the wedge. The racks can be staggered, as pictured in Figure 12, to allow for additional motor space.

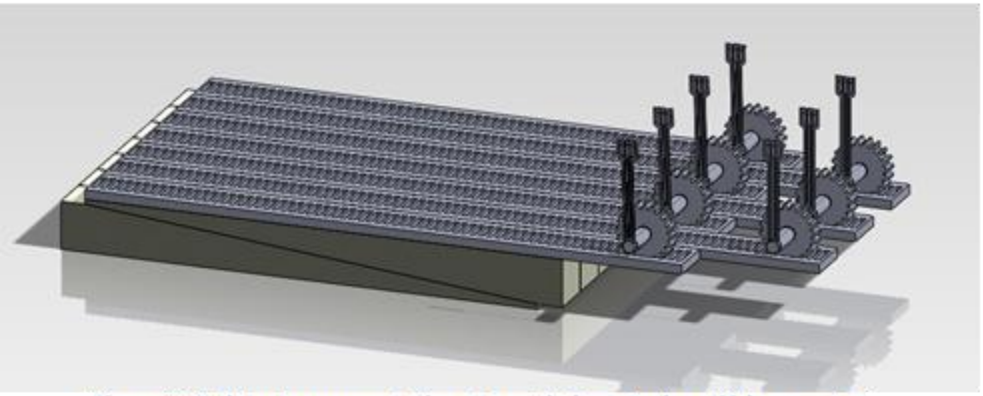


Figure 12: Solidworks representation of a preliminary design utilizing a rack and pinion actuation method with Tungsten wedges.

The motors for the preliminary design are Brushless DC Servomotors, which allow for ample speed (46,500 rpm No-load speed) and torque (0.356 mNm) to be coupled with a proper gear system to actuate the wedges consistently and precisely [26]. Since the motors are servo motors, they will be able to provide sufficient position feedback, as required by our clients. The exact motor model will be determined after the wedge material has been chosen and careful force calculations have been made.

ERGONOMICS

The International Ergonomics Association has defined ergonomics as “the understanding of interactions among humans and other elements of the system in order to optimize human well-being and overall system performance” [27]. This prototype is a proof of concept to Siemens, so that this device could potentially be built within a future CT machine. Since there will be no human interface with this device, there are no major ergonomic factors.

ETHICAL CONSIDERATIONS

The main ethical consideration for this project is that no harm comes to the patient or the doctor during the duration of the procedure. If the design were to be implemented into future CT scanners, it must remain relatively light in weight and fashioned securely so the device does not move as the scanner revolves quickly around the patient. This would ensure that the calibration of the scanner is not effected, and that there is no risk of the device coming loose. However, the prototype will only be used as a proof of concept and will not be implemented within the scanner. Instead, it will be fashioned to a table as an object is revolved to simulate an actual scan. Because of this, there are no major ethical considerations for the scope of this prototype.

FUTURE WORK

FABRICATION PROCESS

The team is currently in contact with Wire Works Engineering, LTD in order to obtain exact quotes on the manufacturing and sourcing of the aforementioned wedge material choices. Once these prices are received, the team will present them to our clients for a discussion of the optimal material to purchase. As soon as the material is selected, an order must be placed to have the wedges manufactures using wire-electro-discharge machining (wire EDM) [28]. While the order is being fulfilled, the team must run various force calculations to ensure a proper motor with sufficient torque is selected, and a corresponding rack and pinion system must be selected.

HOUSING AND TESTING

Once the inner workings of the device are finalized, a housing enclosure must be constructed. The housing must contain all components while maintaining access to parts in preparation for future maintenance. The entire device must also be able to fit within the Artis Zeego CT machine’s source housing, restricting the dimensions to roughly 25.4 by 25.4 centimeters. Programming of the device will then be done by our clients, including all reconstruction and feedback algorithms. Finally, the device is to be tested using CT phantoms, to analyze whether the CT equipment is functioning properly by imitating known properties of the human body [29]. This will allow us to quantitatively determine the improved signal to noise ratio when using the dynamic beam attenuator.

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APPENDIX A – MATLAB CODE A

```
kV = [1:150]';
sigPatient = sum(kV.*phi_tube100.*exp(-muBone*1 - muSoftTissue*36));

meanEPatient = sigPatient/sum(phi_tube100.*exp(-muBone*1 - muSoftTissue*36));

t = zeros(1,92);
meanELeaf = zeros(1,92);
for z=1:92

  func =@(x)-sigPatient+sum(kV.*phi_tube100.*exp(-A{z,1}(1:150,9)*density(z,2)*x(1)));
  t(z) =  fzero(func,[-0.0001 260000000]);
  meanELeaf(z) = sum(kV.*phi_tube100.*exp(-
A{z,1}(1:150,9)*density(z,2)*t(z)))/sum(phi_tube100.*exp(-
A{z,1}(1:150,9)*density(z,2)*t(z)));
end

figure;semilogy(t);
figure;plot(meanELeaf - meanEPatient);


muAl = A{13,1}(1:150,9)*density(13,2);
muFe = A{26,1}(1:150,9)*density(26,2);
muW = A{74,1}(1:150,9)*density(74,2);
muCu = A{29,1}(1:150,9)*density(29,2);
muPb = A{82,1}(1:150,9)*density(82,2);

muBone =
muRhoCompound{spektrCompound2C('Bone'),1}(1:150,9)*densityCompounds(spektrCompound2C('
Bone'));
muSoftTissue =
muRhoCompound{spektrCompound2C('SoftTissue'),1}(1:150,9)*densityCompounds(spektrCompou
nd2C('SoftTissue'));

figure;semilogy(1:150,muAl,'--',1:150,muBone,'-');xlabel('Energy
(keV)');ylabel('Linear Attenuation Coefficients (cm^{-1})');zlabel('Path Length
(cm)');
title('Linear Attenuation Coefficients');
hold on
semilogy(1:150,muFe,'--r');
semilogy(1:150,muW,'--m');
semilogy(1:150,muCu,'--c');
semilogy(1:150,muPb,'--k');
semilogy(1:150,muSoftTissue,'-r');
legend('Aluminum', 'Bone', 'Iron', 'Tungsten', 'Copper', 'Lead', 'Soft Tissue');
hold off
```

APPENDIX B – PROJECT DESIGN SPECIFICATIONS

Digital Beam Attenuator (Beam Attenuator)
Project Design Specifications
02/06/2012

Group Members: Michael Scherer, Katherine Lake, Clara Chow, Ashley Mulchrone
Advisor: Professor Paul Thompson
Clients: Dr. Charles Mistretta and Timothy Szczykutowicz, Medical Physics

Problem Statement: In X-Ray Computed Tomography, a uniform X-Ray beam is used despite the fact that the transmission though the patient varies significantly due to the patient's anatomy. For almost any clinical or proposed medical x-ray imaging system, either a proposal for intensity modulation (IM) exists in literature or a form of IM is implemented clinically, but these forms of IM are limited in that they cannot adapt the incident photon flux over time to match all projections. The use of a uniform X-Ray incident beam results in a non-uniform signal-to-noise ratio, a sub-optimal distribution of X-Ray scatter, and significantly higher or lower dose than necessary to some regions of the body. Since current devices are only able to statically attenuate the X-Ray beam, we propose to design and actuate a series of dynamically attenuating wedge pairs placed between the X-Ray source and the patient. The attenuating wedges will use the changing thickness of the wedge pairs to locally attenuate the incident beam, which will result in improved image quality and reduced X-Ray dosages.

Client Requirements:

- A new prototype shall be designed and manufactured.
- The system shall linearly actuate the prototype.
- The wedges of the prototype shall move in response to pre-programmed positions.
- The wedges of the prototype shall move independently.

1. Physical and Operational Characteristics

A. **Performance requirements:** The device shall alter the strength of the X-Ray beam as a function of position for the duration of the Computed Tomography (CT) scan. The device must move at a minimum speed of 15 mm/s. The prototype must actuate the wedges to satisfy a dynamic range that encompasses the entire X-Ray beam.
B. **Safety:** The prototype must not be harmful to the researcher, user, or patient. The prototype must not harm the machine or interfere with its intended operation. It also must be self-contained during the duration of the scan.
C. **Accuracy and Reliability:** The actuator must be able to move the wedges within 1 mm of accuracy.

D. **Life in Service:** The device will be a prototype and thus has a limited life in service. The device shall have a life in service of one year of frequent use. If implemented clinically, the device must have a life in service equal to that of the CT scanner.
E. **Operating Environment:** The prototype is to be used by graduate students and professor in a CT research lab. During testing, the device will be exposed to X-Ray radiation; therefore, design components must be resistant to X-Ray damage.
F. **Ergonomics:** There are no ergonomic concerns relating to the prototype.
G. **Size:** The prototype shall be as small as possible while maintaining full functionality. It must be large enough to attenuate the X-Ray beam throughout the entire dynamic range at a minimum of 31.75 cm from the X-Ray point source.
H. **Weight:** The prototype shall be as lightweight as possible while maintaining an appropriate level of X-Ray attenuation.
I. **Materials:** All parts shall be resistant to damage by X-Ray radiation. The wedge material shall be homogeneous in order to uniformly transmit X-Rays and correctly attenuate the X-Ray beams. It shall also slide with a low coefficient of friction.
J. **Aesthetics, Appearance, and Finish:** The device is a prototype and therefore functionality is the dominant consideration over aesthetics and appearance.

2. Production Characteristics

A. **Quantity:** One prototype shall be produced.
B. **Target Product Cost:** The budget for this semester is $5,000.

3. Miscellaneous

A. **Standards and Specifications:** The final product will require the approval of the Food and Drug Administration and clinical trials. The prototype is a proof of concept and therefore will not require government approval.
B. **Customer:** The intended user is a medical professional or researcher who will utilize Digital Beam Attenuation to improve CT image quality during a medical procedure or for diagnostic purposes.
C. **Patient-related Concerns:** As our design may eventually be commercially available for medical professional use, it should follow all restrictions enforced by the Food and Drug Administration. It must not cause any harm to its user.
D. **Competition:** No other forms of Digital Beam Attenuation exists at this time. Statistical CT image Reconstruction is also being used to create better quality CT images, but that technology is currently in development. In addition, static devices like bowtie filters are currently being used to attenuate X-Ray beams on CT scanners.