Animal Bed Controller

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Abstract

An animal bed positioning system is to be developed for an open source micro CT, PET, and RT system. This positioning system must have at least five degrees of freedom including translation about all three axes, as well as rotation about the x and y-axis. This system must be very precise with step sizes of 100 microns for translation and 0.1 degrees for rotation. The system was broken up into two parts: the XYZ translator and rotation about the other two axes. It was decided that linear actuators are to be used for the XYZ translator and that stepper motors will be used for rotation. The latter was determined with a design matrix.

Background

Current medical practices often require medical imaging and treatment systems to diagnose and treat patients, for example x-rays, CT, PET, MRI, etc. Medical research is often conducted on animals, testing new drugs and procedures with the goal of improving health care for people. These animal patients (such as mice and rats) are smaller in size than humans, and require scaled down versions of the systems used with human patients.

Micro CT, micro PET, and micro RT systems have been developed to better image and treat the smaller bodies, organs, and tumors of animal subjects. These systems function analogously to those used on humans, however with finer resolution imaging and treatment. They are also smaller and less expensive than the systems used on humans. To achieve precision in imaging and radiation treatment, precise patient positioning is required in the imaging and treatment fields.

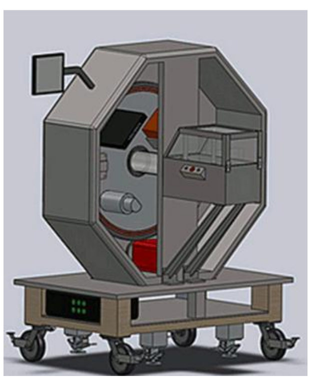

Figure 1: Complete micro CT/PET/RT system being developed by the

Our client, Surendra Prajapati, is a graduate student working on the Open-Source Medical Devices project at Morgridge Institute for Research. This project is working to create an open source small animal imaging and radiotherapy system with micro CT, micro PET, and micro RT (Figure 1). Because it is open source, the design for this system will be freely available and will be less expensive to build than buying a commercially available system.

Our group will be designing the motion control system that will be used to position the small animal. The user will attach the animal bed (which secures the sedated animal) to our motion control system in the loading area, then use the control system to move the animal into the imaging bore. Once inside the imaging bore the motion control system will precisely positioned the animal bed in the imaging field. The motion control system will be designed to be more precise than positioning systems in commercially available imaging systems by incorporating more degrees of freedom, and also to be less expensive to keep the cost of the entire imaging and therapy system low.

Motivation

CT and PET scan systems can be very useful devices for research. Dr. Matthew Jensen and the rest of his team of research assistants use the Siemens Inveon micro CT and PET scanner, in the Wisconsin Institutes of Medical Research, weekly. They use the device to measure stroke volume and glial scarring in rats [Ostergaard Interview]. The combination of the two systems allows for the subject to only have to be put under anesthesia once to get two separate images. There are other devices on the market, but these systems can cost upwards of a million dollars. Our client is currently designing an open source system that will hopefully cost fractions of that. He would eventually like to put all of these designs and specifications on the webs, thus giving many more the opportunity to share their research and ideas with the world.

Problem Statement

Nowadays, image scanning devices such as the CT, PET, and RT scanner could cost up to several million dollars. These medical devices can only be afforded by big hospitals or research centers with considerable financial capability, when they too are needed for medical research in other places, especially in developing countries. Currently existing scanning systems also are constrained by the numbers of degrees of freedom, as they can only perform translational movements in two directions. As needs for more detailed medical research, disease analysis and physical check rise, a CT, PET, and RT scanner model that can be obtained in a easier and more affordable way would be ideal so that more people are able to participate and contribute more in any medical field involving these scanners, which they might not be able to perform in the same way nowadays due to financial constraint. In addition, this model should be more task-oriented and consists of more degrees of freedom including one more direction for translation and two for rotations, which allows more in depth looking into testing subjects. A model described above can be acquired by lowering down its cost of materials, and assembling new components for more degrees of freedom.

Client Requirements

The animal bed must fit into a 12 cm diameter borehole. The bed must have translation along all three axes as well as rotational movement about the x and y-axis. The system must be able to move 75 cm in the z-direction, or into the machine, with a precision of .1 mm or 100 microns. It must also have this same precision along the x and y-axes but only up to 1 cm. It must have rotational precision up to .1 degree up to five degrees on both sides. If it is possible, the design should incorporate a heat pad.

Existing Devices

There are currently small animal imaging and radiotherapy systems commercially available which incorporate small animal positioning systems in their designs. However these positioning system designs usually have fewer degrees of freedom than our client requires and/or are more expensive than is desirable for an open source project. Two examples include the Siemens Inveon system and Johns Hopkins University's SARRP.

Our group went to see the Siemens Inveon system (Figure 2) at the Wisconsin Institute for Medical Research. Inveon is a modular system that can combine micro CT, PET, and SPECT. This system had only two degrees of freedom, z and y translation. It utilized motors which turned screws to move the platform into and out of the imaging bore and vertically up and down.

Figure 2. Siemens Inveon system. <http://www.medical.siemens.com/siemens/en_GB/gg_nm_FBAs/files/broch/br_09_inveon.pdf>

Another example of a small animal imaging and radiotherapy system with a positioning system is the Small Animal Radiotherapy Research Platform (SARRP, Figure 3), which was developed at Johns Hopkins University. It has 4 degrees of freedom (X, Y, Z, and yaw/θ) and does both CT and RT. Xstrahl Ltd has commercialized the SARRP system (Verhaegen).

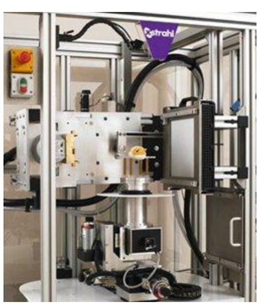

Figure 3. SARRP system. <http://iopscience.iop.org/0031-9155/56/12/R01/pdf/0031-9155_56_12_R01.pdf>

Ethics

Image scanners are applied to generate three-dimensional image of living subjects' complex interior for further body examination or disease analysis. This process highly requires sharp precision; as a result, although one of the objectives about this open source project is to make the total cost as low as possible, this micro CT/PET/RT scanner still should be able to perform with high accuracy, and for at least a certain lifetime. Therefore, design methods and material selections are crucial and should still be chosen in priority based on the feasibility and reusability of the potential product. Cost will be considered at last to adjust excessive precision. Specifically, components for three translational and two rotational movements have to at least achieve the required precision specified by the client.

Ergonomics

The design should be convenient and safe for the user to operate. During typical operation the user will only have to attach the animal bed to the motion control system and close the loading area cover. However, the user may need to adjust or replace parts of the entire system; for this reason the design should include parts that are fairly easy to change and no sharp edges.

After attaching the animal bed and closing the loading area, the user will interact with the interface of the design to control the bed's position. This will take the users input and use it to move the animal bed. Our design will probably use a prototyping microcontroller such as an Arduino to convert the input to a movement. This could be integrated into the imaging and radiotherapy system's interface once the entire system design is finished.

Design Proposal Overview

A system is being designed to give a specimen table or animal bed five degrees of freedom with high precision to allow a specimen to be situated in exactly the same position for each imaging or therapy session. This design will be part of an open source small animal imaging and therapy system that includes micro CT, PET and RT scanners. The five degrees of freedom this design is required to move in are X, Y, Z, yaw and pitch. The animal bed needs to move 65 cm in the Z direction from the starting position to the bore of the scanner. Once at the bore, the animal should travel another 35 cm in the Z direction to be position at the CT scanner. After the CT scanner, there is an additional 45 cm in the Z direction that the animal bed must move to reach the PET. The animal bed needs to have the ability to reposition 1 cm in the position and negative X and Y directions. This system is required to have 0.1 mm or 100 micron precision in the X, Y and Z planes. The animal bed also must be capable of rotating ±5° with 0.1° precision in both the yaw and pitch directions. The overall system should be designed to allow a user to precisely and easily position the animal bed. The design should also permit the animal bed to be facilitated with probes and equipment to measure specimen's vitals and keep it alive and unconscious during imaging and therapy sessions. The designs below focus on accomplishing the five degrees of freedom the table will move in by splitting the linear and angular motion designs. The first design accomplishes the X, Y and Z linear motion the animal bed will move in. This X, Y, and Z system can be attached to one of the three alternative designs for the angular motion, yaw and pitch, to give the system five degrees of freedom. Each angular motion design provides a unique movement process.

X, Y, Z Linear Actuators

The focus of this design is the movement along the X, Y and Z axes and provides three of the five required degrees of freedom for the overall system. This design uses three separate linear actuators that each move along one three dimensional plane. These three actuators will be secured together, as in figure 4, to form a system that will allow for a specific (X, Y, Z) coordinate to be reached. Using this type of configuration, the animal bed will be able to be move along the X, Y and Z axes.

Figure 4 shows three actuators secured together

Since this design configuration will need to support the weight of several components such as the other two linear actuators, the animal bed, the specimen and the design for angular motion, a liner slide, a type of linear actuator, will be used to move along the Z axes. This linear slide will provide the overall system with a sturdy support. A linear slide also supplies the system with long, precise movement along the Z axes that uses position feedback to ensure its positioning (Zaber, 1997). These advantages that a linear slide provides, helps to fulfill some client requirements.

The other two actuators will only need to each move a net distance of 2 cm but must be able to fit within the bore of the system and have sufficient strength to move the remaining system. Therefore, to move in the X and Y directions, electro-mechanical linear actuators will be used. These actuators operate by using DC or stepping motors to extend and retract in a repeatable manner (GlobalSpec, 1999). These actuators are also cost effective, come in a variety of sizes and have a positive feedback system to provide the required accuracy (GlobalSpec, 1999). Due to these factors, electro-mechanical linear actuators satisfy client requirements and provide the movement along the X and Y axes.

Using a linear slide for movement along the Z axes and two electro-mechanical linear actuators for the position in the X and Y plane, this design successfully satisfies the client requirements. This configuration also provides the system with three of the five required degrees of freedom. These actuators will need a motion controller to manipulate the movement of the actuators. This will allow a user to move the linear actuators and adjust the animal bed into different positions.

Design 1

For the first design, inspiration was drawn from a pig roast, which is where we get the name "The Spit". However, instead of rotating about the x-axis, the two ends would be on linear actuators and could then rotate about the y-axis. By changing the z distance of the two linear actuators, an axis of rotation would be created at the center of the animal bed, which would be ideal for our client but not preferred.

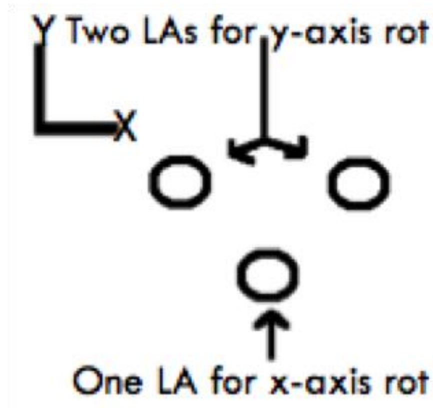

Figure 5 shows the position of the three linear actuators in design 1, in the xy plane.

The entire system would consist of three linear actuators with the third being in the middle and slightly below the other two. This linear actuator would account for the rotation about the x-axis. This would be possible with a connection made at the front of the animal bed through a system of hinges. If this linear actuator were to slide forward, it would push the front of the bed up. If it were to slide backward, it would pull the animal bed down. After a few calculations were made, it was shown that a step size of 87.3 microns would allow for a rotation of .1 degrees about the y-axis.

Because all three linear actuators would be moving in the z-axis and all three would need to have very small step sizes, this system would allow a greater precision. If all three linear actuators were to be moved together, it would simply slide the bed forward or be pulled backwards. Another benefit of this system is that there will be extra strength in the y direction because of the connection underneath the system, which is shown to the right in the yz plane. When an animal is put onto the end of the bed, a small amount of deflection will be seen. However, because of the extra stabilization, this deflection will be very small and hopefully would be immeasurable.

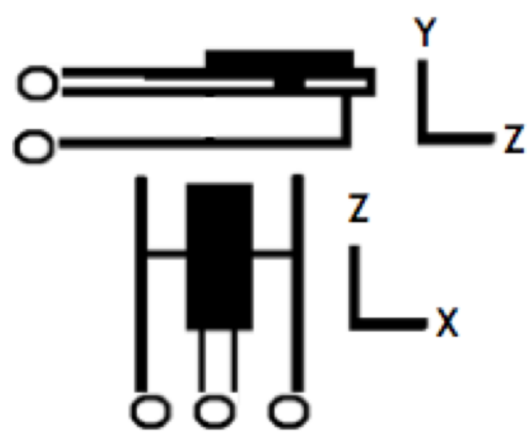

Figure 6 shows design 1 in both the xz plane and the yz plane

But by no means is this system perfect, it only accounts for two DOF and has three linear actuators. This may lead to being more expensive than it needs to be because these linear actuators must have very small step sizes and be very strong. This system would also require a design for a platform to be made. This platform would need to hold all three linear actuators and would add extra weight to the end of the system. This extra weight would add to deflection in the y-axis and would require our xyz-system design to be even sturdier. Also, if it were to be within our clients guidelines of fitting into the 12cm borehole, it would need to be made very small, making the rotation of the bed difficult.

Design 2

This design is called Springs and Strings. It creates the pitch and yaw rotations by segmenting the end of the arm that extends into the imaging bore with bearings. The bed is on the end of the arm, and rotates around the bearings, as shown below. These bearings are orthogonal to both each other and to the length of the arm.

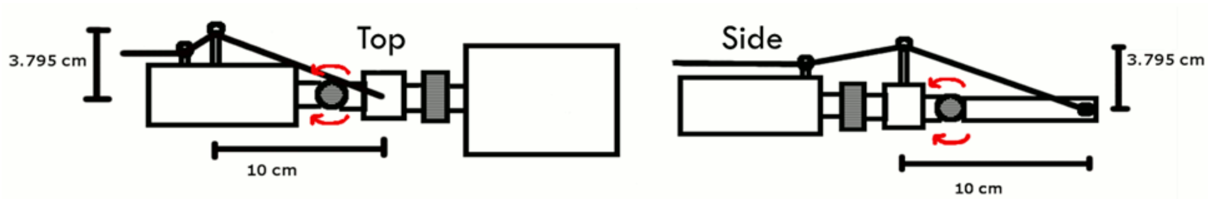

Figure 7 shows design 2 in the xz plane(left) and the yz plane(right)

The bed is held in place by opposing forces around each bearing. The force in one direction is created by a helical torsion spring attached to the arm on both sides of the bearings. The opposing force is supplied by a string. One end of the string is anchored to the rotating end of the arm, and the other runs to a linear actuator through a pulley system. The string pulls against the spring around the bearing, with the position of the linear actuator determining the angle that the bed is at. Each linear actuator's position is controlled separately by the user's input. Each bearing requires its own spring and string/pulley/linear actuator system. The linear actuators are anchored to the xyz axes positioning system, away from the end of the arm.

One advantage of this design is little weight is added at the end of the arm because the linear actuators can be moved away and connected by the pulley system. This creates less deflection than a heavier design, which would affect the y-axis position of the bed. Another advantage is that there will be little image attenuation because the only material in the image field will be the animal bed and a small section of string. This design requires no solid supports under the animal bed.

The major disadvantage of this design is that it creates non-constant changes in angle (0.0944o to 0.1o for dimensions given in Figure x with a linear actuator step of 0.006 cm). The linear actuator creates a constant change in string length, which creates varying changes in angle because the point the string is attached to rotates around the bearing at a constant radius. While the linear actuator's step size and the distance between the string attachment site and the pulley can be selected to create a maximum angle change of 0.1o (as in Figure x), this complicates the calculations needed to determine the angle of the bed. Another disadvantage of this design is that because it rotates around the bearings and not a point centered on the animal bed, it creates relatively large translations in the x, y, and z directions. These translations would then have to be corrected for by the linear axes positioning actuators.

Design 3

This design applies two hybrid stepper motors to perform pitch and yaw rotation. The two motors are linked with a bracket, one on the top and the other one at the bottom, with the top one connecting to the animal platform as shown in figure 8. The bottom motor will be placed on a base, where linear actuators can be easily attached. The bracket is chosen so that each motor can act independently without changing the angles the other one generates. There is more than one type of stepper motors; hybrid stepper motor generally costs the most among them due to its ability to generate higher torque and resolution, or smaller step angle (degrees/step).

Figure 8 shows two stepper motors linked with a bracket, connected to the bottom of the animal bed.

Stepper motors are operated with an open-loop system, which make them purely rely on a direct input from an external driver connecting to the motors to create an output on the motors themselves [Circuits Note]. Open loop system eliminates costs for sensing and feedback devices such as optical encoders [Circuits Note]. The external driver, also called motor controller, can receive information from computer codes and send digital signals of amounts of impulse to the motor, which are the only sources driving it to move. The diagram of how open-loop system works can be seen in figure on the right [Anaheim Automation]. Amounts of impulse are positively proportional to numbers of step angle stepper motor rotates. These two features make stepper motor easy to control in terms of degrees of rotation, as users only have to input the impulse corresponding to them.

Other than easy to control, model with stepper motors also prove being capable of accomplishing required tasks. As shown earlier in the client’s requirement, this scanning model needs to generate turning angles with a precision of 0.1 degree. Stepper motor qualifies this requirement by utilizing its step angle with the motor controller. Different coding on the controller can make each step angle further divisible by up to two hundred fifty six, when each step angle of a stepper motor ranges from 0.9 to 3.6 degrees. Precision of approximately 0.0035 degree sufficiently fulfills the specification. In addition to precision, most stepper motors sold also are capable of generating at least 180 newton-meter of torque,

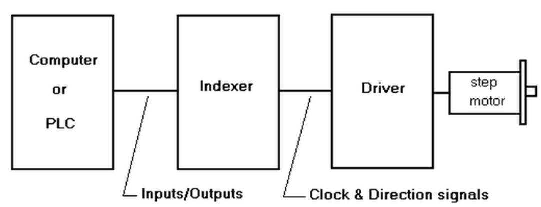

Figure 9 shows the flow of commands from the computer to finally the step motor when the approximate animal platform weighs 500 grams, or about 70 newton-meter of torque. Therefore, model designed with stepper motors theoretically is feasible for the minimum requirement.

Besides the two greatest strengths, easy controlling and feasibility, this model also provide additional benefits. First of all, the two stepper motors are independent from any movements other than pitch and yaw, which impose no possibilities that rotations will interfere translations or the other way around. In other words, x,y,z actuators can just be attached to the bottom motor with no concerns. Moreover, this design is reusable as stepper motors do not wear off easily. Unlike other motors with internal brushes that might corrode motor themselves when being operated, stepper motors rotate through changing of magnetic field due to changing of impulses. This gives stepper motors relatively longer lifetime. Lastly, the cost for this design is inexpensive, as the main components are only two motors and one motor controller. Additionally as mentioned earlier, the feasibility of this design exceeds that of minimum requirement significantly; this is a point where the balance of feasibility and cost can be adjusted to make a prototype that not only qualifies its purpose, but also less expensive.

Design Evaluation

To evaluate the three alternative designs for angular motion, a list of criteria for these designs was developed which includes: accuracy and precision, cost, repeatability, lifetime and feasibility of each design. These categories are weighted depending on their importance to the design and client requirements with a design able to receive a maximum score of 100. Using this grading system, table 1 is a design matrix that was created to help select the angular design to be combined with the X, Y and Z linear actuator system to produce the final design.

Category	The Spit	Springs & Strings	Stepper Motors	Weight
Accuracy/Precision	20	19	22	25
Cost	15	20	20	25
Repeatability	18	12	18	20
Lifetime	17	15	17	20
Feasibility	5	6	9	10
Total	75	72	86	100

The most important design and client requirement was the accuracy and precision the system will have. This is important to giving the system the ±5° with 0.1° precision in the yaw and pitch angular direction. Therefore, this category received a weight of 25. The spit design requires some extra pieces to be made and depends on the accuracy of 3 linear actuators which gives it a score of 20. Springs & strings received a score of 19 for accuracy since it has non-constant changes in angle, it loses some precision. The stepper motors design received the highest accuracy and precision grade of 22 because it only depends on two stepper motors that have the ability to be precise.

The cost was also a very important aspect to the overall design of the system. Since the system will be part of an open source medical device, the price of the design needs to be relatively low to give the opportunity for everyone to be able to purchase the necessary equipment to build the system. Needing three linear actuators and additional equipment causes the spit design to have a high cost. This leads to it having the low score of 15 for this category. Both springs and strings and stepper motors designs only use two motors, which leads to them receiving the same score of 20. Springs and strings are required to be purchased for the springs and strings design; however, the costs of these are negligible compared to the cost of motors.

These angular designs also need be able to perform their motion over and over again. Repeatable motion is a client requirement and will also allow the user of the system to precisely know what to expect the design to do. Therefore, this category received a weight of 20. Both the spit and stepper motor design received a score of 18 due to that fact that they use motors that allow for repeatable motion. The springs and strings design only received a score of 12 due to the fact that the design moves with inconsistent angle change per each step.

Another important aspect to these designs is the overall lifetime that they will have. These designs must last a long time and be able to handle the wear and tear from constant use. Parts should not be wearing out and needing to be replaced and the system should avoid frequent repairs. This will help to keep the cost of the open source system low and allow for experiments to run without hassle. This caused the category to receive a weight of 20. Again the spit and stepper motor design received an equal score of 17. Since the only parts of these two designs that will need to be replaced are the motors, the lifetime will depend on how long the motors will last. Both stepper motors and linear actuators have long lifetimes and shouldn’t need to be replaced often. On the other hand, the springs and strings designs uses pieces of equipment that can wear out. In this design, the springs can lose elasticity and need to be swapped out or the strings can break must be replaced. This causes this design to receive a score of 15.

The final category that the designs were critiqued on was the feasibility to the building of the design. Again, since this is an open source medical device, the system will be built by other individuals. The design needs to be easy to put together to allow for minimal error to occur during assembly, permitting the system to work properly. This category, feasibility, received a weight of 10. The spit design received the lowest score of 5 due to the extra parts needed to be built and complex set up for it to work properly. The springs and strings design also received a fairly low score of 6. Again this design has additional parts but a slightly less complex setup for proper function. The stepper motor design on the other hand is a straightforward and easy setup giving it a high score of 9 for the feasibility of the design.

Adding up all the scores of the criteria, the overall score of each design can be used to select the final design for angular motion. The spit design received a 75, springs and strings a 72 and the stepper motors an 86. Therefore, the stepper motor design will be used in the final design. The final design will consist of the X, Y and Z linear actuator combined with the stepper motors. The stepper motors will need to be configured to the X, Y and Z design to allow the animal bed the five required degrees of freedom. This final design will have the required precision, come at a reasonable cost and satisfy other client requirements.

Future Work

For the remainder of the semester, we will pursue the development and construction of the final system, the combination of X, Y and Z linear actuator design with the stepper motors design. We will first need to purchase two stepper motors, one linear slide and two electro-mechanical linear actuators that will satisfy client requirements. We will also have to purchase a motion controller that is compatible with the motors we purchase and has the ability to be programmed to move each degree of freedom independently. The overall system will need to be configured together, once the motors arrive, to reposition the animal bed in the necessary ways and it must fit within the bore of the scanners. The overall system also cannot interfere and attenuate any of the imaging devices. Once the final design is completed, we will need to test the system in many ways. The most important test will be the animal bed movement precision and accuracy. Using the testing results we will need to refine the design in any necessary ways. Lastly, an interface will need to be developed to allow a user to move the animal bed to precisely position a specimen.

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Project Design Specification Report
Bed Controller
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Date: September 14, 2011
Problem Statement:
To develop and design an animal bed system that will be able to translate in the x, y, and z directions, as well as angular motion. This bed system must be capable to work in micro CT, micro PET, and micro RT systems. Must design a platform for mice that can move in the treatment area. The bed must have at least five degrees of freedom: movement in all three axial directions and rotation about the x and y-axis. The bed system should also be made with oxygen and isoflourine ducts to keep the subject unconscious. If possible design should incorporate a heat pad and other vital readings during the treatment like: heart rate, blood pressure, temperature, etc. In addition, shielding of the animal bed system may be required to attenuate the treatment X-rays. Our positioning system must be made with a low-density material and made so that it does interfere with the imaging systems. The specimen bed should be designed so that the specimen is positioned in the same way each time for imaging or therapy.

Client Requirements:
- Should have 5 DOF, all 6 if possible: rotation about the x-axis, y-axis, and movement in the x, y and z direction
- Should have movement with 0.1mm precision up to 1 cm in xy and up to 75 cm in z
- Should have rotational movement up to 5 degree with 0.1 degree precision on both sides

Design Requirements:
1. Physical and Operational Characteristics
a. Performance Requirements: A mouse or similar sized animal will be lowered onto the device from above and then will be moved into the machine, along the z-axis, by our positioning system. Our positioning system must be very precise to place our animal in the same position as the last test.
b. Safety: The client’s device will include an x-ray system, so we may have to come up with a shielding method.
c. Accuracy and Reliability: Our animal positioning system must have precision in the x, y, and z-direction of 100 microns up to 75 cm in the z-direction, and 1 cm in the x and y-directions.
d. Shelf Life: Will be incorporated into the client’s imaging system so it will need to work many times.
e. Operating Environment: The holding device will undergo both CT and PET scans, but the motor system will remain outside. Our device will be housed inside the client’s device.
f. Ergonomics: Qualified technicians should be using the machine with animals similar in size to a large rat or a small, skinny bunny.
g. Size: The hole in which our bed will be inserted has a diameter of 12 cm, so our bed will be a maximum of10 cm wide to incorporate a cm of movement along the x-axis but will be more likely 5 cm wide.
h. Materials: We need to use a low-density but sturdy material, such as carbon fiber, for the bed as to not interfere with x-rays and stay rigid even at 75 cm.
2. Production Characteristics
a. Quantity: Only one device will be needed
b. Target Product Cost: Our client has not given us a limit. However, he would like us to keep it as cheap as possible so groups looking to build his device will not be discouraged.
3. Miscellaneous

a. Standards and Specifications: The device is an animal positioning system which holds specimen (mostly rats for this project) in an imaging and radiotherapy system for CT micro, PET and micro RT scanning. This positioning system has five degrees of freedom in x, y, z direction and angular motion about the x and y-axis in the imaging and radiotherapy system. General specifications on the functional aspect of this device include:

-Positioning specimen in a particular way all the time on the animal bed.

-Enabling the bed to freely move in and out from the imaging and radiotherapy system in specified distance (75 cm).

-Enabling the bed to translate and rotate in x, y and z direction inside the imaging and radiotherapy system with specified distance (1 cm), angle (5 degrees) and precision (0.1 mm and 0.1 degree)

-Facilitating the system with oxygen duct, isofluorine duct and probes for carrying out certain supplemental tasks during scanning.

b. Customer: The customer mentioned that this animal positioning system is preferred to be in rectangular shape, which would fit better for a rat specimen's physical shape. In addition, the customer pointed out that among the six degrees of freedom for translation and rotation, the function of rotation motion on z-axis would be the least significant and can be neglected if it causes tremendous works or delays on the whole project, as the imaging and radiotherapy system itself can rotate in this way to compensate it. Besides these two points and answering questions, no further ideas and specifications about the project were provided yet. Variations and creativity are allowed and encouraged, which lower down the possibility of existing prejudices.

c. Patient-related concerns: The patient for our design will be a mouse or other small animal. The most important element of our design for the patient will be the oxygen and isoflourine ducts, which will allow the patient to breathe and keep it unconscious. In addition, the patient will need to be fully supported during the scanning and treatment procedures by the stage.

d. Competition: The goal of the project is to make this technology accessible by making this small animal imaging and therapy system design open source and freely available. To do this it should be less expensive than existing systems (both
the entire product and our bed controller design). Examples of existing systems, which include small animal positioning systems, include:

-Siemens Inveon PET and CT scanner: commercially available product, our group will be able to see week of 9/18

-GE Triumph: commercially available PET/SPECT/CT imaging product

-SARRP (Small Animal Radiation Research Platform): Developed at Johns Hopkins and commercialized by Xstrahl, it has a robotic animal positioning system with 4 degrees of freedom (X, Y, Z, and Θ)

-X-Rad 225Cx by Precision X-Ray Inc.: has 3D computer controlled stage, makes automated stage corrections