Interactive Quadruped Animation

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Abstract. An animation system entitled CAT (Cat Animation Tool) has been developed to explore an alternative workflow for novice animation, specifically focusing on quadruped animation. The system adds 3D interaction to the traditional animation pipeline with the intent of easing authoring and thereby widening the authoring audience. Users initially create high-level locomotion by specifying a 3D input curve to which kinematic methods are applied to create locomotion. Subsequently, users layer detailed animation to add expressiveness via 3D input tools. A user study was conducted that indicates embodied motion control decreases the effort required to make complex animation. The results also suggest a proper balance between manual motion specification and automation significantly enhances enjoyment and supports an animator's creativity.

Keywords: Animation Systems, Human-computer Interaction, Quadruped Animation

1 Introduction

Animals possess an amazing ability to evoke human emotion through their body language. They conjure within us feelings like compassion, fear, and companionship – despite not being human. Through their expressive body movement, they communicate intent and feelings without a spoken word. Amateur animators often desire to create such expressive animal motion, but current tools offer a high barrier to access in terms of required expertise and authoring time. We explore an alternative approach for creating expressive animal motion based on 3D interaction and algorithmic support that is intended to open the medium to a wider audience.

In traditional keyframing, the animator specifies primary keyframes and interpolation tangents that are used to generate in-between frames. However, spline curves are not immediately intuitive, and many keys may be needed for a complex interpolation path. On the other hand, interactive animation can capture the desired timing by recording live input. This facilitates expressive animation and nuanced secondary movement since any subtle input movement is automatically recorded.

We have developed an animation system called CAT (Cat Animation Tool) to test a new workflow for creating quadruped animation. Targeted at novices, it allows users to create animations of a house cat using three types of controllers offering varying degrees of control. The top-most controller is an algorithmic controller that generates basic locomotion and jumping which can be parameterized by user input. Below this exist several mulit-joint contollers which control appendages of the cat. For the finest control, single-joint controllers allow direct control over joints.

These controllers capitalize on intuitive mappings between the user's natural body movement and those of the cat using 3D input. Novices are typically uncomfortable animating using low-level single-joint control. We suspect they require control at a higher level and benefit from increased controller degrees-of-freedom (DOF). By grouping control of several joints into high-level controllers and using a 3D input device, typical motions of each appendage can be created efficiently in CAT. The system employs kinematic methods to aid real-time interactive animation and allows a user's own feedback response to drive the animation.

Interactive or embodied techniques for recording motion are likely underutilized in manual animation. Spline-level control of timing is a cumbersome and abstract way to specify movement. By recording natural human motion when animating, higher quality movement can be generated by embodying the task and utilizing natural motor skill.

A user study was conducted to discover the benefits of our approach to novice animation. Participants completed a number of tasks, followed by surveys and an evaluation of the creativity support index [1]. Results indicate that novices liked this approach to animation, and several factors related to user creativity were well supported. A video demostration of this work can be found online.[1]

2 Background

CAT is a specialized cat animation system drawing architectural concepts most notably from Torkos's quadruped work [2] and Dontcheva et al.'s layered animation system [3]. Oore et al. also used 3D input devices to layer recorded kinematic motion over regions of a character [4]. Animation typically requires manual motion specification to create exaggeration and anticipatory effects that defy natural physics. With this in mind CAT explorers kinematic methods when introducing automation. These can be parameterized and iteratively layered to create realistic or non-realistic-looking effects at the discretion of the animator. In particular exaggeration effects are easily layered using kinematics.

Dontcheva et al.'s work showed that animation could quickly be layered even by novices [3], but provided only simple, direct mappings of limited DOFs for animals. CAT builds on this model by introducing high-level control for locomotion and creating a complete workflow for expedited novice animation. When layering animation, choosing a natural or intuitive joint set to control is paramount. Neff et al.'s work showed the value of grouping correlated joints so they can be layered even when using a low DOF controller like a mouse [5]. By switching be-

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[1] Video URL: http://csiflabs.cs.ucdavis.edu/~tmart/movie.html

tween correlation maps quickly, an animator can build complex animation with little experience.

CAT employs variations of several technologies to create full body motion. Of most direct importance is Torkos's work generating locomotion from footprints via optimized constraints [2]. CAT uses kinematics to specify motion trajectories instead of optimization. Torkos's work also used an interactive footprint planner which required the user to directly specify the next footprint position in a walk cycle. CAT alternatively uses an interactive motion path to specify a walk path, and then locomotion is generated from parameters of the walk path.

Coros developed a strikingly realistic subset of jumps and gaits by simulating the internal joint forces of a quadruped [6]. Controlling style and triggering user-directed motion in a physical system, though, is limited, and balancing a character while allowing interactive user input can lead to instability.

However, real-time input bridges the gap between performance animation and physical simulation, yielding a more engaging and expressive animation system. Laszlo used low DOF control via a mouse to control torques of internal joints on a figure [7] and later added predictive input guidance [8]. Similarly, Oore combined physical models and proportional-derivative control to manipulate regions of a biped [4]. CAT uses a more direct approach to input and simply records a user's performance, allowing their movements to generate the overshoot and oscillation effects of physical control and thus avoiding the balance problem common to simulation when introducing user-interaction or attempting to generate physically unrealistic motion.

Other systems have been developed to draw novice users into the animation process. Shiratori and Hodgins used multiple Wii-remotes to specify locomotion and jumps [9]. Users found their interface more enjoyable than traditional joystick and button control. Lockwood et al. developed a gestural system for creating storyboarded animation targeted at directors and non-expert animators by using data gloves and a Vicon tracking system [10].

3 Approach

3.1 User Environment

CAT is designed around a 6-DOF device, called a "wand," that controls character animation, camera navigation, and the GUI. The animation system tracks a Wii-remote and attached reference frame using a Vicon motion capture system. The tracking yields 6-DOFs and the Wii-remote buttons trigger application functions. We achieve visual feedback by projecting the virtual environment onto a wall. The large viewport and our $14'$ x $14'$ physical workspace, defined by the motion capture volume, affords users room to create locomotion paths and explore their body space. CAT utilizes the VRUI VR framework [11], so the animation system is not dependent on specific input or output devices, but rather on 6-DOF tracking support. Low-budget camera or infrared hardware could alternatively be used for tracking. Visually the cat is animated in a virtual world containing a few ramps and a cat scratching post. From the top of the scratching post hangs a physically simulated bird, which the cat can swat in real-time.

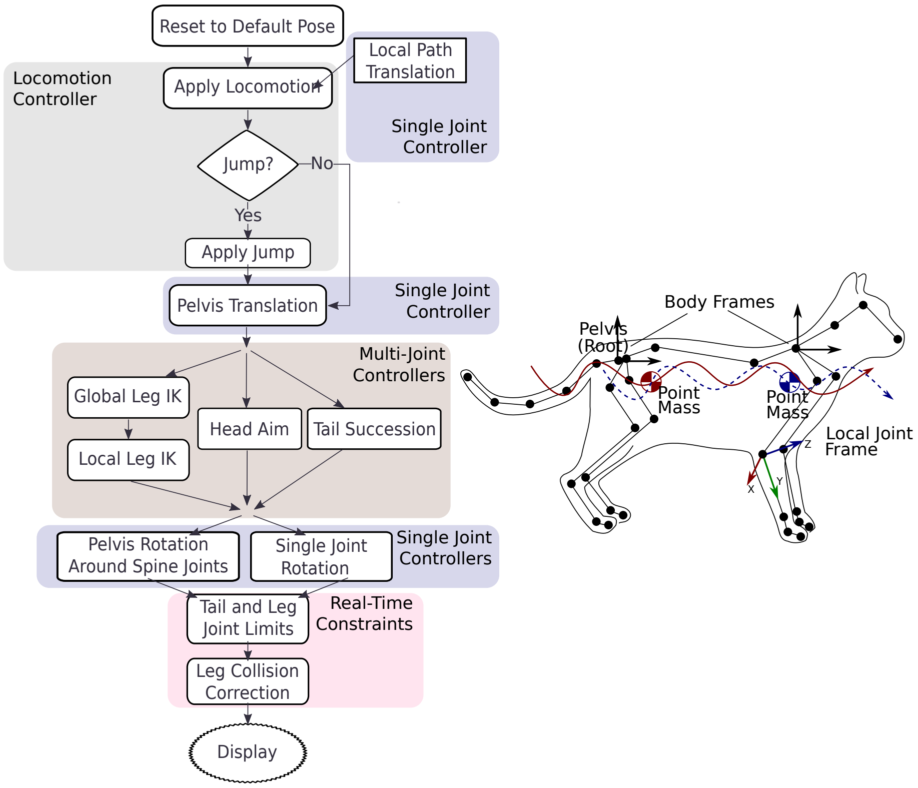
3.2 Workflow

In CAT a user animates a rigid skeleton of a house cat with a linearly skinned mesh attached as shown in Figure 2. User-specified input curves, to be described in detail later in this section, are used by the locomotion generator to create locomotion paths which can include stationary periods and jumps. Next a user can add movement to the limbs, tail, and head using kinematic controllers. The kinematic controllers for the head and tail are custom creations, which allow for typical movement of the involved joint chains. Finally, detailed movement can be layered using single-joint manipulation tools. The pose of the cat is updated every frame according to evaluation of the locomotion controller and layering system, as seen in the flow chart of Figure 1a. Sections of the flow chart will be described throughout this document.

The concept of specialized controllers, kinematic or otherwise, is extensible and dependent upon the application. For the needs of testing novice animation, the tools implemented in CAT represent the base tools necessary to create a complete cat animation with the usual character traits (e.g. locomotion, object interaction, etc.). CAT tries to achieve a balance between managing complex, inter-connected motion and allowing complete control over the skeleton's configuration. To this end CAT adds high-level control of locomotion to a layering system in order to exemplify a type of motion planning that is intuitive to novices. Conceivably, other high-level controllers, for tasks like rolling, could be added. Any new high-level controller, however, should be parameterized by user input and provide predictable results easily understood by a novice.

In CAT, a user should initially create a locomotion path by walking a desired route in the physical workspace. The resulting input should either be a continuous, level curve, or the user can introduce a jump into the motion curve. Once this input curve has been made, CAT filters and processes it, creating a locomotion path that includes standing poses at the beginning and end and gait changes according to the speed of user input. When creating two or more locomotion paths, the user has the option of blending a new path with the last path or creating a new separate path. Adding additional paths is particularly useful if the user wishes to create a path that extends beyond the dimensions of the physical workspace.

Once a path has been created, the user can layer motion on top of the existing path. While the cat is moving, the user can adjust the height of the cat relative to the ground by layering a motion clip with the path-translation layering tool. This adjusts the height of the cat while maintaining all of the locomotion constraints. During locomotion the user can also freely layer head and tail motion using the tools dedicated to these tasks. Once the cat is stationary, the user can generate reach motions for the legs or contort the spine using some of the previously mentioned layering tools. The process then begins anew when the user wishes to add further locomotion to the animation.



(a) (b)

Fig. 1: (a) Flow chart of CAT's control modules evaluated every frame update after a locomotion path has been created. Single-joint controllers affect one joint and occur throughout the evaluation. Local path translation translates the cat relative to its position on the path. (b) Skeleton of cat mounted on trajectories via body point masses.

4 Locomotion

The basic automated locomotion process is to create a footpath according to the input curve, derive trajectory curves for the front and back halves of the cat, and animate over these trajectories. A high level overview of the algorithm will be given here, with full details available in [12]. Torkos [2] used a simplified point mass model to represent movement of the front and back halves, which is likewise used by CAT. These point masses are located at an offset from the pelvis and sternum joints, and trajectories are generated for them as seen in Figure 1b. Locomotion in CAT, employs a parameterized kinematic approach when planning point mass trajectories instead of optimizing physical and comfort constraints like [2]. CAT also adds paw curl, spine contortion, and zero-moment-point correction to the original reconstruction steps used by Torkos.

Level input curves are specified by walking around the workspace. Alternately, a user can define two curves and a jump by continuously walking level, walking a “W”-shaped curve, and walking level again. The bordering level curves each generate locomotion paths and the jump curve creates a procedural jump parameterized by input curve velocity and height.

CAT supports 3 gait patterns typical of quadrupeds: walk, trot, and gallop. CAT uses the concepts defined in the locomotion research of [13] and [14] to generate footprint timings and placements that drive cyclic gait animation.

During each frame of playback the cat is posed on the pelvis point-mass trajectory, and then the spine is configured. A database of precomputed spine configurations is used to pose the spine based on foot position and path curvature. The legs of the cat during locomotion are posed using example-based inverse kinematics. The keyframes of the database use joint angles described in [14] to reflect real extension and contraction angles of a cat’s limbs. Additionally, an under-damped proportional derivative controller is used to simulate natural paw curl during the flight phase of a foot. The last step of locomotion processing per frame is to apply zero-moment point correction to reflect dynamic balance as in [15].

5 Layering

In CAT each layer records motion clips from the wand. A motion clip stores a collection of orientation and position samples over a period of time. Each sample stores an offset transformation in the local frame of a joint with reference to an initial default pose. Successive local clips within a layer are concatenated in real-time to create final joint transformations.

5.1 Controller Concatenation

There are several tools available to create animation for various parts of the cat (e.g. tail-wag, head-aim, global legIK, local leg IK, single-joint rotation tool, etc.), and a full list can be found in [12]. Since locomotion paths are evaluated first each frame, each tool generally layers motion relative to the locomotion pose. By keeping the effect of clips local, many tools can be combined in real-time while avoiding conflicting baked-in poses. CAT represents joints of the skeleton using transformations composed of a rotation quaternion and a translation vector. For most joints the total transformation equation is calculated every frame by concatenating the transformations from multiple system components:

$$\mathbf{J} = \mathbf{LMSC} \tag{1}$$

where $\mathbf{J}$ is a joint’s total transformation per frame, $\mathbf{L}$ is the result of the locomotion controller, $\mathbf{M}$ is the resulting transformation from any multi-joint layers. $\mathbf{M}$ can be the result of the tail-wag layer, head-aim layer, or leg IK layers depending on the joint. $\mathbf{S}$ is the combined transformation from single-joint layers.

C represents any real-time correction of a joint due to ground collision or joint limits. Ground collision only applies to the bottom 3 leg joints, and joint limits only affect the paws and tail-wag controller.

After creating a locomotion path, the path-translation tool can be used to move the pelvis over a path while maintaining footprint and spine configuration constraints. This facilitates layering of manually-defined body effects like momentum overshoot, undershoot, and crouching. Appendages of the cat can be controlled using dedicated tools. A custom head-aim controller configures the head and neck joints, and on the other end of the cat, a tail-wag tool controls the tail. Using the method of [16], a limiting reach window and twist keeps the tail from curling around itself. The legs can be controlled using IK controllers based on Tolani et al.'s analytic inverse kinematics package [17].

Finally, the user can touch-up the animation using single-joint rotation tools. Once all the layering tools have been evaluated, joint limits are applied to ankles and wrists to confine the valid range of motion via [16]. Additionally real-time collision correction keeps the paws from penetrating the ground, giving the user a sense of puppeteering. Because the CAT has many layering tools, detailed explanation of each is omitted but can be found in [12].

6 User Study

To better understand how novice animators perceive automation-aided animation, a user study was conducted. The study consisted of 10 participants from the ages of 19 to 30, and 6 of the participants had no previous animation experience while the remaining 4 did. Each was individually guided through a detailed tutorial of CAT, composed of 5 stages which explained various software features. Every stage of the tutorial was followed by a sample task and CSI survey to determine users' experiences with previously taught features. The CSI (creativity support index) is a metric used to determine the degree to which a tool supports the creative process (Section 7). Roughly one hour was allocated for the tutorial which included verbal explanation, visual/demonstrated explanation, and a practice period in which users could test the explained features. Another hour was allotted to task completion, and 30 minutes was allotted for surveys.

The first of the 5 tasks was to create a locomotion path that included a walk, trot, and gallop in one continuous sequence (*gaits task*). Next, the users were taught to create a jump using the specific input pattern required to trigger jump processing (*jump task*). Afterwards users were introduced to the path-translation tool which moves the body of the cat over previously created locomotion paths, showcasing the reactive and real-time nature of joint configuration over a locomotion path. In addition the users were shown the effects of the tail wag tool and head-aim tool. Once the users' were comfortable with these features they were given the task of creating a "happy" locomotion (*happy task*). The users were to hopefully employ all the above tools to create an expressive animation. Next, the users were taught to use the inverse kinematic leg controllers in order to hit the bird toy hanging from the cat post (*bird task*). Finally, participants were taught to use the fine-grain single joint tools to add details and expression. The users were then asked to create an animation which would stand the cat on its hind legs and swipe at the air as if the cat where swatting at a bug (*hind task*).

CSI surveys after each task were used to evaluate the newly introduced tools. Since the tools affect differing numbers of joints, the CSIs tracked user response to different levels of automation. Participants completed a final CSI at the end on their overall experience and answered additional survey questions.

7 Results and Discussion

In each CSI survey users ranked how well CAT supported 6 factors considered in the creativity literature to be intrinsic to tools which enhance creativity [1]. The 6 factors are exploration, enjoyment, collaboration, expressiveness, immersion, and results-worth-the-effort. Collaboration has no meaning in the context of CAT because it is a single-user tool. Users were first asked to answer 2 banks of 6 questions pertaining to the factors of creativity, which can be found in [1]. Answers are on a 0-10 scale, rating from “high disagreement” to “high agreement.” The final factor score is then the sum of the 2 questions per factor. Next users were asked to answer 15 comparative questions which yield importance rankings for the factors from 0-5. Once the factors have been ranked a final score is calculated by first multiplying the factor score by the importance count. These products are then summed and divided by 3 to yield a score within 0 to 100. The CSI equation which accounts for 6 creativity factors follows:

$$CSI\ Score = \frac{\sum_{i=1}^{6}((a_i + b_i)c_i)}{3} \tag{2}$$

where a_i and b_i are the first and second ratings for each factor and c_i is the importance count of each factor.

7.1 CSI Survey Results and Analysis

The CSI results indicate that users enjoyed CAT, and the tools facilitated expressivity. The means of all task ratings, as can be seen in Figure 3, were significantly higher than 50%, the neutral score. The breakdown of individual creativity factors is listed in [12]. The factor count data shows exploration, enjoyment, expressiveness, and results-worth-the-effort to be the most important creativity factors.

The means in Table 1 show the mean percentage of perceived fulfillment F_i for each creativity factor before being scaled by the count. This percentage is calculated using an average of the two factor rating values, a_i and b_i:

$$F_i = \frac{(a_i + b_i)}{20} * 100. \tag{3}$$

Figure 3 depicts some interesting results from the data of various CSI surveys. Enjoyment and expressiveness factors rated highly per task, but the happy and bird tasks were found to be the most enjoyable. Survey responses reveal that users enjoyed these two tasks because the tools were well embodied and directly responded to user movement. The bird task in particular rewarded the user with reactive visual feedback when the paws contacted the bird. The happy task required the user to layer an animation from locomotion through appendage movement. The tail and head layering tools required little explanation, and their learning curve was small. The path-translation tool used to position the cat over paths was well received by users and provided good visual results for the effort. These tools were deemed the most creatively expressive even though more expressive movement can be achieved using single-joint tools at the expense of time.

This reflects the point that novices require a level of automation adequate to convey their creative intentions and commensurate with their skill level. Fine-level control is often not desired particularly if realism is not a priority. Even so, the novice user seemingly enjoys remaining involved in the creative process and not simply triggering animation. Interestingly, some users with animation experience enjoyed the fine-level control mapped to the wand using single-joint layering tools. They reported it eased the task of specifying timing constraints, and animation could be layered more quickly than using traditional keyframing.

In the survey responses participants indicated that the happy task was the most enjoyable and fun locomotion task (gait, jump and happy tasks include locomotion). Most likely the users are responding to the sense of embodiment when using these tools. The wand provides intuitive control of the head and tail, and minimal effort is required to produce quality animation. The other locomotion tasks require less input, but there is little room for artistic expression. The generated locomotion, however, was typically deemed worth the effort.

The immersion mean rating was lower than the rest of the creativity factors. This hints at the learning curve associated with CAT as the system has many features and the wand has 13 buttons. Only once users have memorized the functionality will they likely feel immersed.

The jump task received the lowest mean CSI score, likely because users had trouble drawing the correct input curve. Often when performing the task the users exceeded the capture volume and had to redraw the curve. Conversely, the happy locomotion task received the highest average rating perhaps in part because understanding of the tools involved was immediate.

The mean scores for each task were around 75% except for the bird task which was 80.2%. The factor breakdown reflects higher ratings for exploration than other tasks in addition to high values for expressiveness and enjoyment. The standard deviation was moderate for several of the CSI score averages, seemingly due to the diverse backgrounds of study participants. Some had animation experience while others had technical backgrounds, and still others were non-3D artists. From the CSI results it is apparent that the expectations of novice users cover a wide range. Consequently, the factor count averages generally showed high standard deviation. It seems the users in the sample group have wide-ranging weighting of creative factors, and a larger sample population is needed for more conclusive analysis regarding ranking of creativity factors.

7.2 Likert Survey Results and Analysis

Table 2 shows results of several Likert-scale questions designed to gauge user's reactions to the system. The Likert results indicate that users felt CAT enhanced creativity and enabled users to create original animation beyond the pre-defined tasks. Since users felt confident that they could create new animations, it can be assumed that the training session was of adequate length, and the general user interface was acceptable. Automation of several joints was preferred to single-joint control as expected.

One surprising result was that some users would prefer mouse and keyboard control for fine-grain control, particularly when controlling a single joint. Unfamiliarity with the wand and muscle fatigue probably impacted this result as CAT requires the user to stand and gesticulate with the arm.

Even though a learning curve was evident, users were able to create reasonable animations for all tasks. Achieving the appearance of proper balance on the hind task was difficult but the most fun according to one user. In addition several users mentioned it was pleasurable to be free of the mouse and keyboard and instead use greater body movement to record animation. It is expected that with more practice most users would agree that greater embodiment is advantageous compared to a mouse and keyboard.

8 Future Work

A broader study would be useful in verifying the results for novice users as a whole and would help verify the role of embodiment within the animation context. With respect to features, marker-free visual tracking of user limbs, as opposed to optical motion capture, would allow a user to map her arm onto a character's appendages unencumbered by suit or tracking devices. Although motion capture systems offer powerful performance animation capabilities, their application to novice animation is limited by expensive equipment and a lack of convenience. Microsoft's Kinect [18], however, offers a possible affordable platform for novice animation technologies. Also other infrared technologies can be used for 6-DOF tracking since CAT is built on VRUI [11], which uses device abstraction to allow for various virtual reality setups. Aside from animation and gaming, CAT could be used for stroke rehabilitation therapy because it utilizes basic motor skills to generate complex motion, which would break the monotony associated with traditional rehabilitation tasks.

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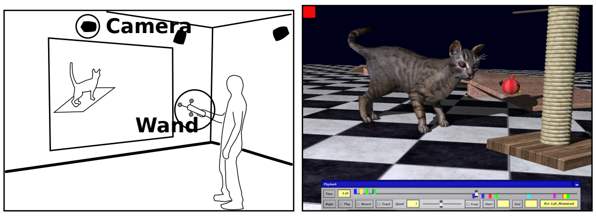

Fig. 2: Physical workspace and picture from CAT animations.

Task/Statistic	Gaits	Jump	Happy	Bird	Hind	Overall
CSI Score μ (%)	74.5	74.3	80.2	76.2	75.8	79.2
Score σ	11.8	18.0	16.4	22.6	18.8	17.8
Score P-value	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

Table 1: Creative support index statistics. Counts are averages of the two questions per factor from the CSI. P-values are calucated by comparing the CSI mean to a 50% expected CSI rating using a one-sample t-test.

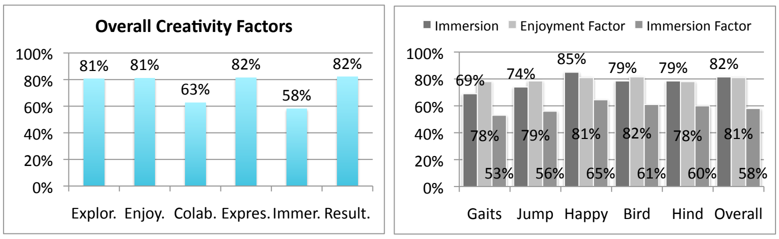

Fig. 3: Graphs showing mean Overall CSI scores for each factor and mean scores for select creativity factors over the tasks. The Overall CSI is an extra CSI survey used to rate the creativity of CAT as a whole.

Question	μ	σ	**P-value**
1. I enjoyed using CAT.	4.5	0.278	<0.01
2. CAT's wand was intuitive to use.	3.9	0.989	<0.01
3. I enjoy automation of several joints versus single joint control.	4.7	0.233	<0.01
4. CAT's automation impacted my creativity.	4.0	0.667	<0.01
5. If it was possible, I would rather control CAT using a mouse and keyboard.	2.6	1.156	not significant
6. I was able to create my desired motion using CAT's tools.	3.7	1.122	<0.05
7. Using CAT I could create an original animation(ie. not created in the directed tasks).	4.3	0.456	<0.01

Table 2: Likert questions. Strongly Disagree=1, Disagree=2, Neutral=3, Agree=4, Strongly Agree=5. Questions 1, 2, 3, 5, 7 use a "Strongly Disagree - Strongly Agree" scale. Question 4 uses a "Strongly Hindered - Strongly Enhanced" scale. Question 6 uses an "Almost Never - Almost Always" scale. A one-sample t-test was used to calculate p-values. Test statistics were compared to an expected value of 3.