STOP-MOTION ANIMATION: TOWARDS A REALISTIC 3D CAMERA MOVEMENT CONTROL

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In stop-motion camera animation the camera is slightly moved between frames, and once these are assembled, it produces an illusion of movement. We are concerned with improving the existing stop motion camera animation practice. To this end we present a survey on its current state of the art, and present an "ideal" process for stop motion camera animation in order to develop an animation interface capable of producing realistic camera moves.

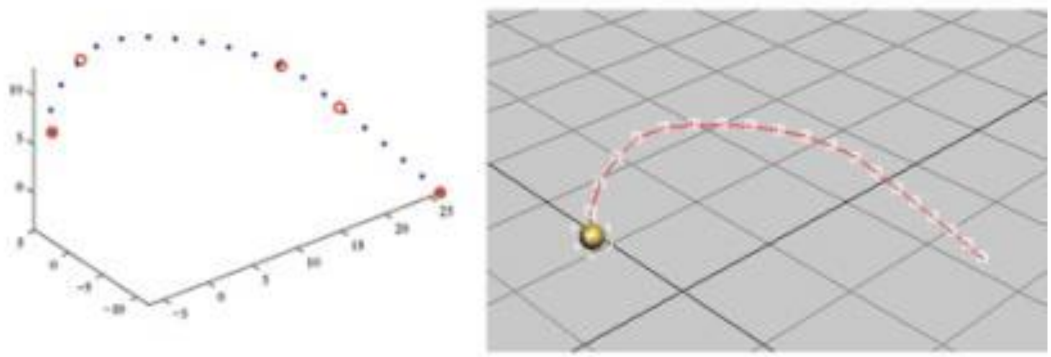

Fig. 1. Left image: the entire parametric Hermite quintic space curve interpolating the keyframes (red circles) and parameterized by equally spaced arc length parameters (blue points). Right image: Motion curve of left image imported in 3D Studio Max.

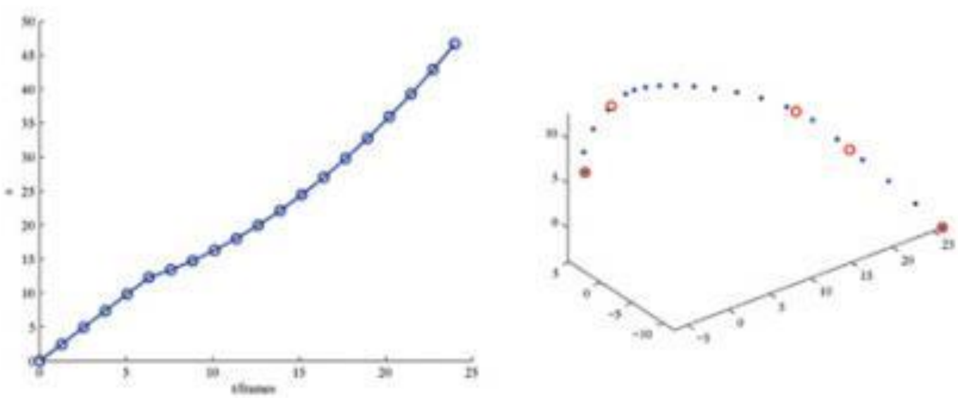

Fig. 2. The Figure in the left shows an Ease curve composed by a linear (s1(t) = t for 0 = t = 6) and a parabolic part (s2(t) = t^2 for 6 < t = 24). The Figure in the right shows the corresponding parametric Hermite quintic space curve.

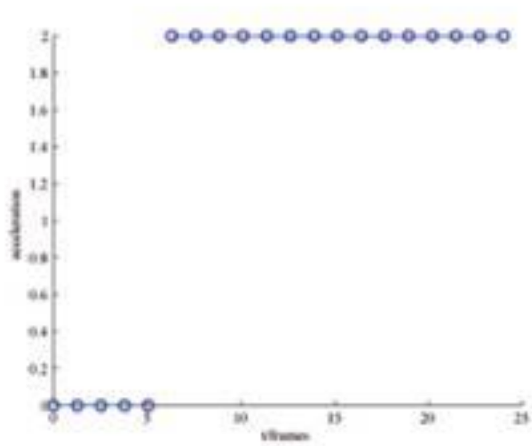

Fig. 3. The acceleration curve corresponding to the parametric space curve in Fig. 2.

1. Stop Motion & Camera Movements: A State of the Art

Almost as old as cinema itself, stop motion is a method of animation that brings any object (model, puppet, clay, etc.) “alive”, making it appear to move on its own. By manipulating objects through a series of still positions, photographing each position on a still camera and then playing these as a continuous sequence, the illusion of movement is created. It’s a (very) long and (very) tedious process. To complicate the matter, if an animator does a mistake on stage, it is not possible to go back and repeat parts of a movement as it can never be recaptured exactly in the same way. With these constraints, animating the camera is a hazardous task. It is almost an impossible job to move the camera frame by frame along a perfect curve to produce a smooth move, mainly because the slightest imprecision produces an unnatural shake in the final sequence. And, unlike on real stage, there is no way to make several shots and choose the best one as the process is too long: a talented stop motion animator can handle only a few seconds of animation per day:

1. *"An animator's day is structured around the few seconds he will shot, and the delay is judged to be a long one if it is about twelve seconds or maybe an easy day if it is only four seconds long..."* explains Barry J. C. Purves. [1]

For a long time, these technical constraints forced directors to fix the camera on stop motion sets. On the contrary, on real stages since W.D. Griffith in the beginning of the 20th century, camera movements are mainly recognized as part of the aesthetic cinematographic specificity. In order to overcome this frustrating status, stop motion animators first tried to find hand-made tricks that could give more freedom to the camera, but these increase the complexity of the production workflow. In 1993, to obtain the same camera move freedom as on a real stage, Henry Selick used for the first time a motion controlled camera for *“Tim Burton’s The Night before Christmas.”* Comparing the two ways to move a camera in stop motion, we can resume the benefits and disadvantages of each animation process:

- **Hand positioning**: it can work for one axis of freedom (unusually two, like the travelling and panoramic move in *"The Secret adventure of Tom Thumb,"*David Borthwick, 1993) but no more than two degrees of freedom as the process would become too complex and hazardous; it works well with linear acceleration moves but is not precise enough to handle acceleration ease in and out, or slow moves; adds unnatural shakes to the move because of the human hand lack of precision which on the other hand confers the specific quivery stop motion aesthetic. Some examples of such moves can be found in *"9.99$"* (Tatia Rosenthal, 2008), *"Fantastic Mr Fox"* (Wes Anderson, 2009) or shorts like *"Western Spaghetti"* (PES, 2008) and *"MUTO"* (BLU, 2008). In *"Peter and the wolf"* (Suzie Templeton, 2006), animators even tried to simulate a camera on the shoulder shot for a subjective view of the wolf.
- **Motion control**: as these devices are intended for live stage, their characteristics are far too sophisticated for stop motion needs in terms of speed, size, weight and cost; the device's trajectory is computer controlled by 3D curves such that the camera executes perfect moves. On the one hand this is a blessing for the stop motion process as it prevents from any shake caused by animators' mistakes or imprecisions. On the other hand, this doesn't correspond to the stop motion aesthetic since it constrains the stop motion move to appear as perfect and lifeless as a computer interpolated move. The following movies have used a motion controlled camera: *"Wallace and Gromit: A grand day out"* (Nick Park, 1989), *"Corpse Bride"* (Tim Burton and Mike Johnson, 2005), *"Wallace and Gromit: The Curse of the Were-Rabbit"* (Steve Box and Nick Park, 2005) *"Wallace and Gromit: A matter of loaf and death"* (Nick Park, 2008), *"Coraline"* (Henry Selick, 2009), and also the 2011 advertisings TV campaign for the Brother printers.

In this context we cite Peter Lord (see e.g. [2] and [3]) *"Stop-frame is like live music, played on traditional instruments, compared to a studio recording using the finest instruments in the world, all the latest technology and some electronic instruments. The latter is more polished, more perfect, bigger, better, showier - but maybe lacks humanity. Stopframe is much less perfect, much less polished, unrepeatable, inaccurate - in a word, human."*
This analysis allows us to conclude that a certain limited amount of "shakiness" is desired as it provides realism to the stop motion movie but the process of hand positioning the camera is a too tedious and slow task. We are thus interested in a motion control system specifically designed for stop motion that is able to simulate a realistic (hand made) camera animation. To this end we first review the existing tools for camera animation in section 2 and then describe the first steps towards a new system for controlling camera movements for stop motion in section 3.

2. Existing Tools for Camera Animation

As our new system's objective is to allow precise camera moves on stop motion stage, it is not possible to use hand positioning. Thus, existing software like Stop Motion Pro [4], [5], iStopMotion [6] or Dragon Stop Motion [7] are not relevant as they only can control camera settings and not camera moves. This section shortly reviews the state of the art for 3D animation of camera movements. We are aware of the following 3D animation software programs: Maya, 3DStudioMax, Lightwave, Blender, Cinema4D, Softimage, Houdini. These programs have two main tools to animate an object: "Keyframing Animation" and "Path Constraint Animation".

- "Keyframing Animation" is based on the traditional animation technique, where the user only sets the important frames, called keyframes, and, using interpolation techniques, the software program generates the intermediate frames, called in-betweens. The object's trajectory is internally represented as a parametric space curve where the animator interacts with its three coordinate curves *x(t), y(t)* and *z(t)* in order to change position as well as speed. Note that position and speed can not be modified separately.

- "Path Constraint Animation" separately constructs the 3D space trajectory and the so called Ease Curve that controls the object's speed.

The main advantages and disadvantages of these tools are:

- Keyframing Animation:
  - Separation of position and speed: Not possible
  - Global/Local control of space trajectory: Only local control
  - Addition of constraints: Possible
  - Space trajectory's x-y-z-coordinates accessible: Yes
- Path Constraint Animation:
  - Separation of position and speed: Possible
  - Global/Local control of space trajectory: Only global control
  - Addition of constraints: Partially possible
  - Space trajectory's x-y-z-coordinates accessible: No

As far as the mathematical background is concerned there exist several interpolation techniques to fit a piecewise curve to a sequence of given points (keyframes), depending on the final motion desired. The most used techniques in animation may, e.g., be found in bibliography of [8]. In order to overcome the major disadvantage (dependence of position and speed) of the most popular animation technique, the "Keyframing Animation", several approaches aim at reparameterising the curve by arc length and thus controlling the movement along the curve by an Ease Curve, see bibliography of [8]. The author of [9] adds so called displacement functions in order to modify the space trajectory as well as the Ease Curve.

3. Experimental Environment for a New System

We present an experimental environment for a new system conceived to overcome the existing drawbacks of the traditional animation methods in 3D software animation programs. In particular we will focus on "Keyframing animation" and we will tackle the following issues: separating position and speed of the trajectory curve and proposing a representation that allows us to add constraints of real camera devices such as ranges for curvature, acceleration and deceleration. As recalled in section 2, the most used interpolation methods in animation give the possibility to control only first order derivatives at the junction points of the piecewise interpolant. To get a smooth trajectory curve that takes into account the constraints of a real camera move, every curve segment should be defined in terms of tangent and curvature vectors at its endpoints. To this end we consider the class of piecewise G2 continuous interpolants where each curve segment is described either by a parametric Hermite quintic or by a rational Bézier cubic, like the one described in [10]. For the mathematical details see [8]. As concerns the problem of separating position and speed of the trajectory curve we proceed as follows. Using existing numerical techniques (see references in section 2) we parameterise the entire curve by arc length, such that a unit change in the parameter value results in a unit change on the trajectory. See Fig. 1 for an illustration. Thus, by using the concept of the Ease curve, which represents arc length over time, we can choose the speed at which the curve is traversed, see Fig. 2. Moreover, also the acceleration curve is controlled (see Fig. 3).

Currently, an experimental environment to test our system has been implemented in *Matlab*®. Given a sequence of points and chosen the desired parameterisation, the program computes a G2 Hermite quintic space curve and gives the possibility to change the speed along the curve without modifying the trajectory. Vice versa, it's possible to modify the trajectory without changing the parameterisation.
The points of the new parameterisation computed by *Matlab*® are given in input to 3D Studio Max by an external script and the new trajectory is visualized in the Motion curve window (see Fig. 1, right).

On the basis of this first step, our objective is to elaborate a system (e.g. by integrating the above process in an interactive interface in an animation program such as 3D Studio Max) that gives stop motion directors and animators full camera move freedom and respects the handwork visual aesthetic of stop motion. In particular we are aiming at the following system properties:

- The 3D animation part should allow to simulate a 3D camera move that can integrate constraints and imperfections (noise) of real camera devices (louma, steadycam, dolly, crane, etc.). The classical keyframe or path constraint animation should first be split in a position curve and a speed curve. Different parameterizations could then be applied separately to these curves and simulate, rather than imitate, the behaviour of a real camera device. The positions of the virtual camera should then be exported frame by frame to the motion control system.
- The motion control software, once these data have been imported, should allow to calibrate the motion control robot, to control the camera settings and, finally, to execute the sequence. It should also give some options to enhance creativity: frame by frame shooting for classic stop motion, automatic sequence shooting for timelapse, multiple takes with different camera settings for each frame (for HDR shots or Depth of field stacking).
- Last, the motion control robot should be affordable for any-sized budget production, handle a 2Kg camera, and have at least 1/10th of a millimeter precision for positioning and 1/10th of a degree precision for rotating.

We've already built two versions of the motion control robot. The first one moves on one translation axis and respects the required precision for a 300€ budget. Images of this robot and videos of several stop motion tests can be found at www.crealyse.com/recherche/dossiers. On the basis of this first version, a second "upgraded" robot has been built which is able to move on one translation axis and two rotations axes, respecting the required precision and for a 400€ budget. We are now working on the motion control software and tests have been scheduled for the next months.

4. Conclusions: Benefits of the Whole System Workflow

Computer graphics and SFX software have already simulated many cinematographic visual specificities to strengthen the illusion of reality: adding digitally generated motion blur, film grain, lens flares or glow let the spectator think that what he or she is looking at is real and not computer generated. Being able to simulate the influence of floor irregularities, human manipulations and mechanical imperfections of a camera device on a 3D camera movement would also contribute to the illusion of reality. Thus a motion control system specifically designed for stop motion would be a benefit for all types of stop motion productions: "specifically designed" means that it should be adapted to stop motion stages in terms of size and weight, accessible to any-sized budget productions and give animators enough control to stylize the camera movement. With an optimized workflow, such a system would significantly encourage creativity while respecting the handwork aesthetic of stop motion, intensify cinematographic illusion by giving life to camera and allow as much freedom for camera moves as on a real stage.

References and Notes:

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