A Visuomotor Coordination Model for Obstacle Recognition

Tomoyori Iwao

Waseda University
3-4-1 Okubo, Shinjuku-ku
169-8555, Tokyo, Japan
sazabi@akane.waseda.jp

Akinobu Maejima

Waseda University
3-4-1 Okubo, Shinjuku-ku
169-8555, Tokyo, Japan
a.maejima@kurenai.waseda.jp

Hiroyuki Kubo

Nara Institute of Science and Technology
8916-5 Takayama, Ikoma
630-0192, Nara, Japan
hkubo@is.naist.jp

Shigeo Morishima

Waseda Research Institute for
Science and Engineering
3-4-1 Okubo, Shinjuku-ku
169-8555, Tokyo, Japan
shigeo@waseda.jp

ABSTRACT

In this paper, we propose a novel method for animating CG characters that while walking or running pay heed to obstacles. Here, our primary contribution is to formulate a generic visuomotor coordination model for obstacle recognition with whole body movements. In addition, our model easily generates gaze shifts, which expresses the individuality of characters. Based on experimental evidence, we also incorporate the coordination of eye movements in response to obstacle recognition behavior via simple parameters related to the target position and individuality of the characters's gaze shifts. Our overall model can generate plausible visuomotor coordinated movements in various scenes by manipulating parameters of our proposed functions.

Keywords

visuomotor coordination, obstacle recognition, general versatility

1 INTRODUCTION

Obstacle recognition is an important aspect of computer-generated (CG) animation, for example, perceiving a puddle of water on the ground while walking or running. In general, this appears to be a simple problem involving characters responses to static or moving obstacles. Such movements are well-researched in the character animation field, however, coordinating eye movements in response to obstacles remains an unaddressed problem. Further, although eye movements have been researched in several areas, such as computer graphics and physiology [Arg76a, Arg65a, Bec89a, Col00a, Den07a, Mat03a], analyzing or generating realistic eye movement is a challenging task. In this paper, we propose a visuomotor coordination model for obstacle recognition that simultaneously measures and analyzes eye and whole body movements. As shown in Figure 1, our model can efficiently generate realistic cognitive movements by designating the obstacle position. Further, our model is artist-friendly in terms of representing characteristic gaze shifts, for example, consistently maintaining a gaze with a human continually looking downward.

Human Walk.

Understanding and modeling human walk is well-researched in several areas, including physiology and robotics. Humans often walk to search for something or to reach their destinations. Similarly, in CG scenes, numerous characters walk for the same purposes. Therefore, modeling actual human walking is crucial to synthesize realistic CG character walking. Particularly, obstacle recognition modeling while walking is significant because CG characters usually observe some object while walking.

To understand how humans recognize obstacles while walking, collecting and studying human data is necessary. Therefore, we observed humans recognizing obstacles while walking and, simultaneously measured the arm, foot, body, and head movements via a motion capture system. In addition, we measured eye move-

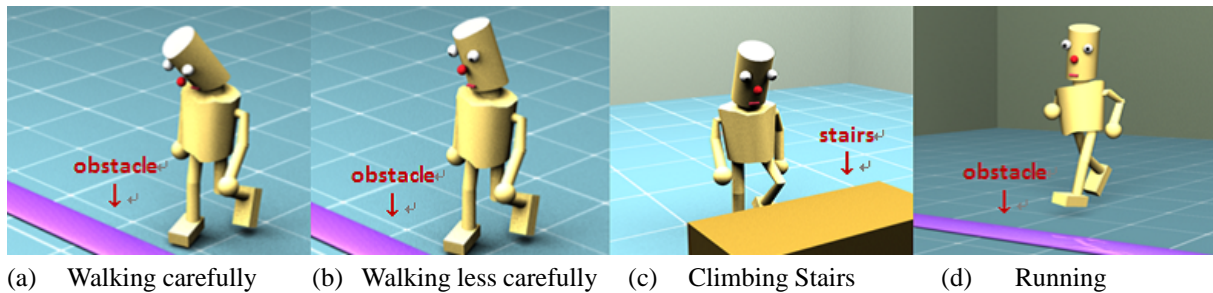| (a) Walking carefully | (b) Walking less carefully | (c) Climbing Stairs | (d) Running |

Figure 1: The character recognizes an obstacle while walking or running; synthesized character animations in various scenes were achieved by manipulating parameters of our model, which can also express the individuality of the character; note that movements for obstacle recognition mainly depends on the obstacle's position.

ments via a head mounted eye tracker. This experimental environment is presented in Figure 2.

To measure how the body and eyes respond to an obstacle, the obstacle should be noticeable and its position must be easily estimated from a human subject's perspective. We placed a black 70cm-squared cloth on the floor as an easily recognizable obstacle. In our experiment, a subject approached the obstacle and passed across it. Next, the subject walked away from the obstacle. The subject observed the obstacle while approaching, on the other hand, did not pay heed to it while passing across it or walking away from it. In particular, we observed that subjects naturally walked away from the obstacle.

Actual measurement results of the arm and foot movements are presented in Figure 3; results indicated that the arm and foot move in a fixed cycle while walking. The arm moves forward and backward, whereas, the foot moves upward and downward. These results are observed in ordinary scenes and are often taken for granted in physiology and robotics. CG artists are aware of these movements and easily synthesize such arm and foot movements into their CG scenes.

As illustrated in Figure 4, the head movement shares a strong relationship with the foot movement. Figure 4 indicates that the head moves in the same cycle as the foot movement cycle. Generally, head movements are divided into two types; translation and rotation. In our experiment, the head translates upward and downward with foot movement. Simultaneously, the head rotates upward and downward to recognize the obstacle on the ground or look ahead carefully.

As illustrated in Figure 5, eye movements also share a strong relationship with foot movements. Figure 5 indicates that the eye moves approximately in the same cycle as the foot. However, unlike head movements, eye movements have a subtle time lag to the foot movement. In general, the eye rotates upward and downward much like the head rotation.

Contributions.

In this paper, we propose a novel visuomotor coordination model for CG characters to recognize an obstacle while walking or running. Our model is based on experimental evidence of actual human behavior. This model has two key features: *visuomotor coordination* based on simultaneous measurements using a motion capture system as well as a head mounted eye tracker and *general versatility* for use in various CG scenes to represent the characteristic behaviors of CG characters. Principally, characteristic behaviors are the eye and body movements of CG characters, including the individuality of such characters; e.g., a character might always look downward while walking or not pay heed to an obstacle while walking. To the best of our knowledge, simultaneous measurements of eye and body movements are rarely conducted in the computer graphics field [Yeo12a]. Further, the visuomotor coordination models proposed before have less versatility, i.e., they can be used only in limited CG scenes with object interception such as ball catch [Yeo12a]. Our model is much easier to manipulate for rigging artists because we model obstacle recognition behavior via a function with a set of simple parameters. Moreover, considering the temporal sequence of foot, head, and eye movements is an effective means to naturally produce obstacle recognition behavior in CG scenes.

The rest of this paper is organized as follows. In Section 2, we introduce related work and compare such work with our approach. In Section 3, we create the practical visuomotor coordination model for obstacle recognition based on experimental evidence. In Section 4, we illustrate the solution to our proposed model equations and the application of our model to various CG scenes; we also present how to manipulate parameters in our model to represent specific characteristic behaviors. In Section 5 and the supplemental video, we demonstrate the performance of our model. We discuss the limita-

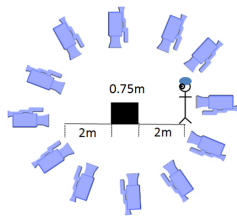tions of our model in Section 6 and conclude our work in Section 7.
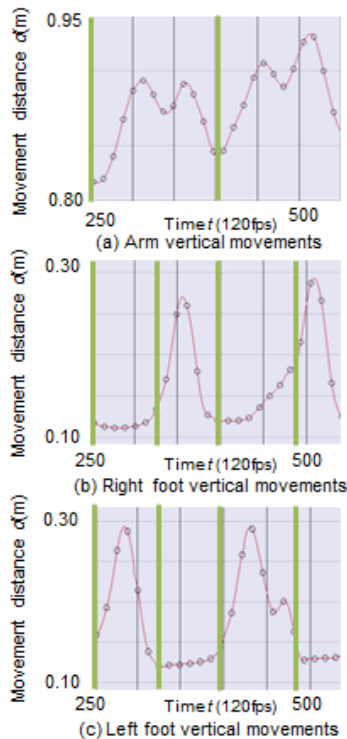

Figure 2: Experimental Environment

Figure 3: Tracking arm and foot vertical movements

Figure 4: Tracking head and foot vertical movements
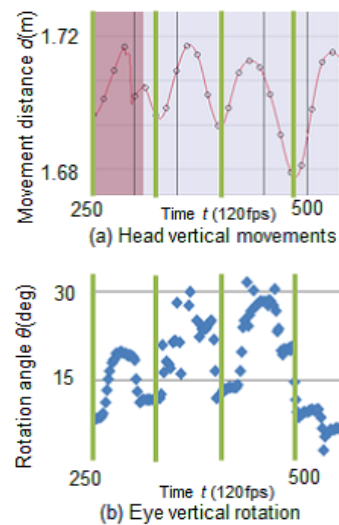
Figure 5: Tracking eye and head vertical movements

2 RELATED WORK

Computer Graphics.

Numerous papers regarding character animation focus on ways to synthesize a character's body motion based on actual motion capture data or inverse kinematics [Bae04a, Hua11a, Kov02a]. These methods can synthesize various motions, including walking and running, however, such approaches cannot simultaneously generate body and eye movements.

A virtual character's gaze is considered an important part of realistic character animation and crowd simulation [Den07a, Fuk02, Gu07a, Iwa12a, Lan10a, Lee02a, Man11a, Pel03a, Wan02a, Sha05a]. Eye movement is sometimes expressed independently because it has complex facilities or features. However, eye movements are synchronized with head movements and, in general, several researchers consider eye movements to be related to head movements [Itt03a, Ma09a, Mas07a].
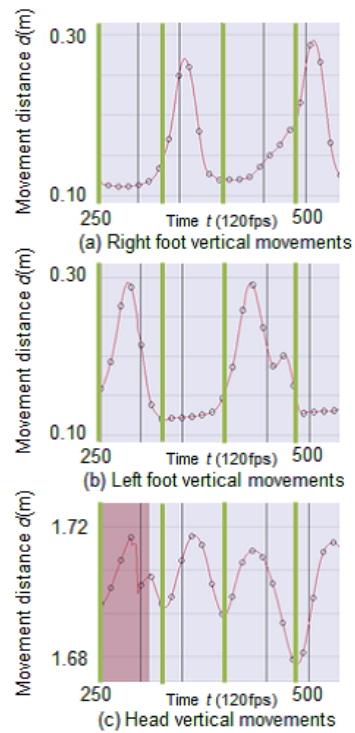
Owing to this, in computer graphics, eye movements are typically modeled only according to head movements. However, head and eye movements should be further related to body movements.

To the best of our knowledge, modeling the eye and body movements simultaneously is a challenging task that is rarely performed [Yeo12a]. Yeo et al. proposed the visuomotor coordination model for object interception. However, their model is only applicable to limited situations such as catching a ball. Ball catch scene is

appeared less frequently than walking scene we focus on in this paper.

Physiology.

Gaze is well researched in physiology because it plays an important part in human behavior and communication [Evi91a, Ike88a, Ike07a, Ken67a, Kur12a, Mar04a, Mat03a]. Gaze shifts while walking is an interesting topic in physiology in which head and eye movements vary according to foot movements while walking [Blo92a, Gro88a, Gro89a]. For example, the head rotates downward when we bend our knees to walk forward. In spite of these sophisticated works, modeling head and eye movements while walking is still not fully adequate. Much of the work to date cannot be directly applied to three-dimensional character animation.

Robotics.

Visuomotor coordination models for walking or for obstacle recognition have been proposed in the robotics field [Bor95a, Hua01a, Zhe90a]. These models are useful and optimized for robots to recognize and avoid an obstacle rather than for generating realistic human-like motion. Therefore, such models are not used for improving the quality of character animation.

3 MODELING

To establish our model, we measured body movement and eye movements simultaneously and constructed our visuomotor coordination model for obstacle recognition. The relationships between the foot, body, head, and eye movements were crucial in constructing our model. The head and eye movements required to be carefully modeled because these movements were highly related to the obstacle. In this chapter, we first independently describe the head and eye movement models. Next, we illustrate the revised model that combines these movements with corresponding body movements and with the influence of the view angle.

Head Rotation.

We divide head movements into two distinct types of movements; translation and rotation. Because head translation is only provided by foot movement while ordinary walking, head rotation is a significant component in expressing movements involved in obstacle recognition. Figure 6 depicts actual head rotation measurements from our experiment. Note that there are some discontinuities in Figure 6 because we remove outliers which have very high value and can be regarded as error data from the experimental result. The dynamic range is set by measuring maximum and minimum of the head rotation angle after removing error data . Figure 7 ∼ 9 are represented in the same manner as Figure 6.

We identified a few key features of head rotation from these measurements. An important feature was the rotating cycle; the head rotated in the same cycle as foot movements. Specifically, the head rotated upward when the foot moved upward and vice versa. The trajectory of the rotation angle is also important; the peak of rotation angle was observed in the middle of a cycle. In other words, the time for upward head rotation was equal to the time for downward head rotation. Moreover, the head was directed toward the front for a longer period of time than downward. Considering the above features and the actual trajectory of the rotation angle, we approximated the trajectory in a cycle by a Gaussian function as follows.

$$\theta_H(t) = \theta_{Hmax} \exp\left\{-\frac{(t-\mu)^2}{2\sigma_H^2}\right\} \tag{1}$$

Here, θ_{Hmax} is a value on the peak of a Gaussian function and, σ_H^2 is the variance of the head rotation representing the initial head rotation angle. Cyclic functions are usually used for approximating periodical movement like walking. However, we found that obstacle direction from subjects varies according to the time course. Thus we need to control the obstacle direction in each cycle. Although cyclic functions have an advantage of manipulating whole movement with a few parameters, we use Gaussian function in this paper to manipulate parameters in each cycle.
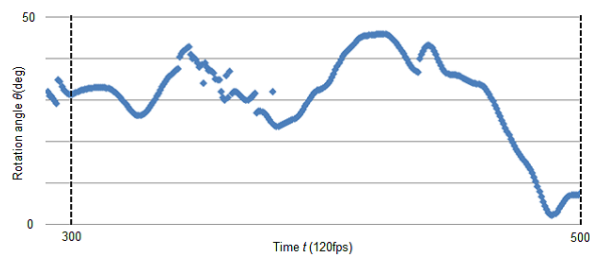

Figure 6: Actual head rotation measurements during obstacle recognition

Eye Rotation.

Eye translation is easily described and followed by head translation, therefore, we only considered the eye rotation. Actual eye rotation measurements from our experiments are presented in Figure 7.

We identified a few features of eye rotation that were similar to that of head rotation. Compared with foot movements, eyes rotated in nearly the same cycle. However, unlike the head rotation, eye rotation included a subtle time lag. As to the trajectory of the eye rotation angle, the shape of the trajectory was similar to that of head rotation. Much like the head rotation, we approximated the trajectory in a cycle via a Gaussian function as follows.

$$\theta_E(t) = \theta_{Emax} \exp\left\{-\frac{(t-(\mu+t_E))^2}{2\sigma_E^2}\right\} \tag{2}$$

Here, θ_{Emax} is a value on the peak of a Gaussian function and σ_E^2 is the variance of the eye rotation representing the initial eye rotation angle.
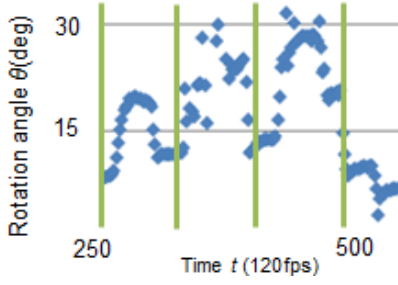

Figure 7: Actual eye rotation measurements during obstacle recognition

Model for Obstacle Recognition.

We approximated each rotation of the head and eye in a cycle via a Gaussian function. Obstacle recognition was highly related to the head and eye rotation. However, body rotation angle and view angle should also be considered for three-dimensional character animation.

Body rotation while walking is easily provided by rigging artists or approximately constant in a short period. It influences a character's direction of gaze. Further, view angle is important to control gaze shifts, especially when humans recognize an object quickly, in which case they tend to look at an object indirectly in the range of their view angle. Because subjects in our measurement paid attention to what was in front of them, i.e., the obstacle, they looked at it indirectly. We combined body rotation, head rotation, eye rotation, and view angle to form our final work; thus, the model for obstacle recognition angle θ_G is described as follows.

$$\theta_G(t) = \theta_H(t) + \theta_E(t) + \theta_B(t) + \theta_V(t) \qquad (3)$$

Therefore, we have the following.

$$\theta_G(t) = \theta_{Hmax} \exp\left\{-\frac{(t-\mu)^2}{2\sigma_H^2}\right\}$$
$$+\theta_{Emax} \exp\left\{-\frac{(t-(\mu+t_E))^2}{2\sigma_E^2}\right\} + \theta_B(t) + \theta_{Vmax} \qquad (4)$$

We incorporated additional features from our observations into the above equation. First, the head rotated with constant rate α against the eye rotation. Second, the energy and burden for head and eye movements increased while humans approached the obstacle because θ_G increased. We assumed that humans use a broad view angle to reduce the burden when they look at a nearby obstacle. By the same reasoning, a broad view angle is used when the cycle is short. Therefore, the final model is described as follows.

$$\theta_G(t) = \theta_{Hmax} \exp\left\{-\frac{(t-\mu)^2}{2\sigma_H^2}\right\}$$
$$+\theta_{Emax} \exp\left\{-\frac{(t-(\mu+t_E))^2}{2\sigma_E^2}\right\} + \theta_B(t) + (\theta_{Vmax} - \frac{l(t)}{\beta}) \qquad (5)$$

$$\theta_{Hmax} = \alpha\theta_{Emax} \qquad (6)$$

4 GENERATING CHARACTER ANIMATIONS

Based on an obstacle's position, our proposed model can generate character animations in various scenes. Our model can also express characteristic behaviors, such as looking downward while walking. In this chapter, we describe how to use our model to generate character animations.

4.1 Solving the model equation

Our proposed equation can be solved in a simple manner. Described above, parameter θ_B is provided by artists or set as a constant. To generate character animation, we require to obtain the trajectory of θ_H and θ_E. From Equation (5) and Equation (6), we have the following.

$$\theta_{Hmax} \exp\left\{-\frac{(t-\mu)^2}{2\sigma_H^2}\right\} + \alpha\theta_{Hmax} \exp\left\{-\frac{(t-(\mu+t_E))^2}{2\sigma_E^2}\right\}$$
$$= \theta_G(t) - \theta_B(t) - (\theta_{Vmax} - \frac{l(t)}{\beta}) \qquad (7)$$

Because θ_{Hmax} is a value on the peak of a Gaussian function, we substitute $t = \mu$ ($= \frac{T_F}{2}$). Further, because time lag t_E is very short, we opt to ignore it; $t_E \doteqdot 0$; therefore, we have the following.

$$\theta_{Hmax} = \frac{\theta_G(\frac{T_F}{2}) - \theta_B(\frac{T_F}{2}) - (\theta_{Vmax} - \frac{l(\frac{T_F}{2})}{\beta})}{1 + \frac{1}{\alpha}} \qquad (8)$$

Finally, we obtain trajectory θ_H, θ_E as follows.

$$\theta_H(t) = \frac{\theta_G(\frac{T_F}{2}) - \theta_B(\frac{T_F}{2}) - (\theta_{Vmax} - \frac{l(\frac{T_F}{2})}{\beta})}{1 + \frac{1}{\alpha}} \exp\left\{-\frac{(t-\mu)^2}{2\sigma_H^2}\right\} \qquad (9)$$

$$\theta_E(t) = \frac{\theta_G(\frac{T_F}{2}) - \theta_B(\frac{T_F}{2}) - (\theta_{Vmax} - \frac{l(\frac{T_F}{2})}{\beta})}{1 + \alpha} \exp\left\{-\frac{(t-(\mu+t_E))^2}{2\sigma_E^2}\right\} \qquad (10)$$

4.2 Obstacle recognition in various scenes

4.2.1 Walking

Obstacle recognition while walking is the same scene as our measurement environment. Generating the animation is straightforward in this case, because obstacle recognition angle θ_G is represented by the following simple manner. In this scene, θ_G is represented as

$arctan\left(\frac{h}{l}\right)$ and the parameter h represents the height of the character. We substitute θ_G and can obtain the trajectory θ_H and θ_E via Equation (9) and Equation (10).

4.2.2 Climbing stairs

A character watches his steps when climbing stairs. This situation seems complicated, however, our model simply generates the animation according to obstacle recognition direction θ_G. In this scene, when a character is climbing a given step, we assume that the character is watching the next step and treat it as an obstacle position in a cycle. The character animation for climbing stairs is generated because θ_G in each cycle is determined.

4.2.3 Running

Like walking, obstacle recognition while running is similar to our measurement environment. The character runs to the obstacle, passes over it, and then runs away from it. The scene is generated by merely manipulating θ_{Vmax} depending on the head or eye rotation cycle times. In general, the vertical view angle reaches $60\sim 80°$. This angle includes both the upward angle and downward angles. In this paper, because the obstacle is on the ground, we only consider the downward view angle and set θ_{Vmax} to $20°$ while walking and $30°$ while running.

4.2.4 Characteristic Behavior

Characteristic behavior is expressed by manipulating parameters α, σ_H and σ_E. Specifically α represents the degree of carefulness; the character walks more carefully when α is increased. Further, σ represents the individuality of the character; for example, when σ is increased, the character is more apt to look downward while walking or running.

5 RESULTS

Using our proposed model, we generated character animations as shown in Figure 1 and the supplemental video. By merely designating the obstacle recognition position, we were able to express character animations in various situations, including walking (Figure 1(a) and Figure 1 (b)), climbing stairs (Figure 1(c)), and running (Figure 1(d)). In addition, we generated characteristic behaviors, e.g., looking downward while walking by changing parameter values of our model.

Validation.

To verify whether our model was able to express human-like movements, we compared the results of our simulation with actual measurement. We recorded the movements of the body by using a 13-camera Vicon motion capture system; further, we recorded eye movements via a head mounted EMR-9 eye-tracker.

The motion capture system recorded whole body movements at 120 Hz, and the eye-tracker recorded eye movements at 60 Hz, which was sufficient for our purpose. In our measurements, subjects first approached the obstacle, passed over it, then walked away from it, as described in Chapter 1 above. Figure 9 compares actual trajectories of head and eye rotation angles with trajectories created via our model. Qualitatively, they look similar and we therefore conclude that our model can express a variety of characteristic behaviors in the experimental environment.

Generalization.

Our model can synthesize character animations for obstacle recognition in various CG scenes, including stair-climbing and walking on the uneven terrain. By changing obstacle recognition positions or parameter values in our model, various character animations can be successfully generated. We captured a subject climbing two steps to evaluate the different movements. Figure 9 compares actual trajectories of head and eye rotation angles with trajectories created via our model. Qualitatively, these results look similar to one another. Therefore, we conclude that our model can be applied to various movements and generate realistic corresponding character animations.
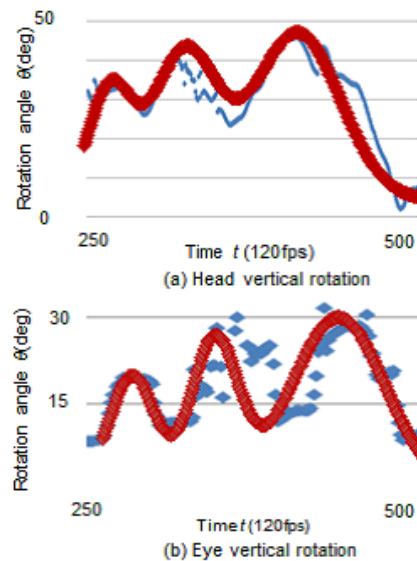

Figure 8: Comparing trajectories of eye and head rotation angles while walking; actual trajectories (blue), trajectories created via our model(red).

6 LIMITATIONS

Our model has a few limitations. We primarily focus on the relationships between the foot, body, head and eye movements, and model head and eye rotations for rigging artists. Therefore, our model is indeed practical for generating character animations. However, our
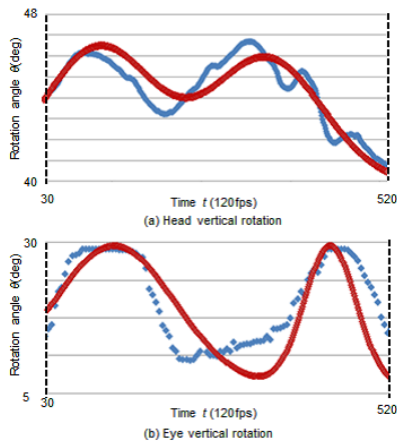
Figure 9: Comparing trajectories of eye and head rotation angles while stair-climbing; actual trajectories (blue), trajectories created via our model(red).

model is rather simplified. We modeled head and eye rotations in a cycle by using a Gaussian function. Other functions, such as a quadratic function or a trigonometric function, may better approximate head and eye rotations. Further, the frequency at which the head and eyes rotate should be probabilistically controlled. Probabilistic control would determine whether the person looked at an obstacle in a cycle and it will generate more sophisticated human-like movements for obstacle recognition. Finally, human and CG character responses to multiple obstacles is an interesting topic. To express character animations that can respond to multiple obstacles, a saliency map method would be a representative approach. Saliency maps are often used in image recognition and gaze control for CG characters because saliency is also useful in computer graphics. Combining our model with the saliency map would enable us to express more complex movements.

7 CONCLUSIONS

In this paper, we proposed a novel visuomotor coordination model for animated CG characters walking or running while paying heed to obstacles. Our model proved the capability to generate realistic human-like motion for obstacle recognition based on simultaneous measurements of the entire body and eye movements, an approach that has rarely been undertaken, especially in the field of computer graphics. Movements in various CG scenes are represented via our model. Characteristic behaviors can be expressed by changing parameter values of our model. Further, our model is easily used by rigging artists to manipulate obstacle recognition points and other parameters.

Although we identified a few limitations presented in Section 6, our model is a novel approach to character animation. Briefly, our proposed method generated

plausible character animations and is applicable to various CG scenes. Our proposed method further improves the quality of current character animation and, will be useful for further research regarding visuomotor coordination in the future.

8 REFERENCES

[Arg76a] Argyle, M., and Cook, M., ”Gaze and Mutual Gaze.” Cambridge University Press, London, 1976

[Arg65a] Argyle, M., and Dean, J., "Eye-Contact, Distance and Affiliation", Sociometry, vol 28, pp.289-304, 1965

[Bae04a] Baerlocher P., and Boulic R., ”An inverse kinematics architecture enforcing an arbitrary number of strict priority levels”, The Visual Computer, Springer Verlag, 20(6), pp.402-417, 2004

[Bec89a] Becker, W., "The Neurobiology of Saccadeic Eye Movements. Metrics", In:RH Wurtz and ME Goldberg(eds), Elsevier Science Publishers BV (Biomedical Division), New York, NY ch.2, pp 13-67, 1989

[Ber07a] Bernhardt, S., and Robindon, P., "Detecting affect from non-stylised body motions.", Affective Computing and Intelligent Interaction, Second International Conference, AC2 2007, Lisbon, Portugal, September 12-14, Proceedings, volume 4738 of LNCS, pp 59-70, 2007

[Blo92a] Bloomberg, J. J., Reschke, M. F., Huebner, W. P., and Peters, B. T., "The effects of target distance on eye and head movement during locomotion.", Annals of the New York Academy of Sciences, vol.656 issue 1, pp.699-702, 1992

[Bor95a] Borenstein, Johann., and Koren, Y., "Error Eliminating Rapid Ultrasonic Firing for Mobile Robot Obstacle Avoidance", IEEE Transactions on Robotics and Automation, vol.11, no.1, pp.132-138, 1995

[Col00a] Colburn, A., Cohen, M. F., and Drucker, S. M., ”The role of eye gaze in avatar mediated conversational interfaces.” Microsoft Tech Report 2000-81

[Den07a] Deng, Z., Lewis, J. P., and Neumann, U., ”Realistic Eye Motion Synthesis by Texture Synthesis”, Data-Driven 3D Facial animation, pp.98-112, December 11, 2007

[Evi91a] Evinger, C., Manning, K. A., and Sibony P. A., ”Eyelid Movements Mechanisms and Normal Data”, Investigate Ophthalmology and Visual Science, vol.32, no.2, February 1991

[Fuk02] Fukayama, A., Ohno, T., Mukayama, N., Sawaki, M., and Hagita, N., "Messages Embedded in Gaze of Interface Agents -Impression

Management with Agent's Gaze-", CHI'02 Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, pp.41-48, 2002

[Gro88a] Grossman, G. E., Leigh, R. J., Abel, L. A., Lanska, D. J., and Thurston, S. E., "Frequency and velocity of rotational head perturbations during locomotion.", Experimental brain research, vol.70, pp.470-476, 1998

[Gro89a] Grossman, G. E., Peters, B. T., Smith, S. L., Huebner, W. P., and Lanska, D. J., "Performance of the human vestibuloocular reflex during locomotion.", Journal of Neurophysiology, vo.62, pp 264-272, 1989

[Gu07a] Gu, E., Lee, S. P., Badler, J. B., and Badler, N. I., "Eye Movements, Saccades, and Multiparty conversations", Data-Driven 3D Facial animation, pp.79-97, December 11, 2007

[Hua11a] Huang, H., Chai, J., Tong, X., and Wu, H. T., "Leveraging motion capture and 3D scanning for high-fidelity facial performance acquisition", ACM Transactions on Graphics, vol.30 issue 4, no.74, July 2011

[Hua01a] Huang, Q., Yokoi, K., Kajita, S., and Kaneko, K., "Planning Walking Patterns for a Biped Robot", IEEE Transactions on Robotics and Automation, vol.17, no.3, June 2001

[Ike88a] Ikeda, M., "*Meha Naniwo Miteiruka?* [What do eyes look at?]",Heibonsha,1988

[Ike07a] Ikegami, K., and Kita, Y., "Interpersonal distance as a function of sex, age, attraction and intimacy",Bulletin of the Faculty of Education, Kanazawa University. Educational science 56, pp.1-12, 2007

[Itt03a] Itti, L., "Realistic Avatar Eye and Head Animation Using a Neurobiological Model of Visual Attention", Tech.rep., DTI Document, 2003

[Iwa12a] Iwao, T., Mima, D., Kubo, H., Maejima, A., and Morishima S., "Analysis and Synthesis of Realistic Eye Movement in Face-to-face Communication", SIGGRAPH'12 ACM SIGGRAPH 2012 Posters Article No. 87, 2012

[Ken67a] Kendon, A., "Some functions of gaze direction in social interaction" Acta Psychologica,26: pp.22-63, 1967

[Kov02a] Kovar, L., Gleicher, M., and Pighin, F., "Motion graphs", In Computer Graphics, SIGGRAPH Proceedings, 2002

[Kur12a] Kurihara, D., Honma, M., and Osada, Y., "Relation between the range of eye contact and individual characteristics in a face-to-face situation", Rikkyo University, Psychology vol.54,pp.51-58, 2012

[Lan10a] Lance, B. J. and Marsella, S. C., "The Expressive Gaze Model: Using Gaze to Express Emotion", Computer Graphics and Applications, IEEE, vol.30 issue 4, pp.62-73, 2010

[Lee02a] Lee, S. P., Badler, J. B., and Badler, N. I., "Eyes Alive", ACM Transactions on Graphics(TOG)- Proceedings of ACM SIGGRAPH, vol.21 issue 3, pp637-644, July 2002

[Ma09a] Ma, X., and Deng, Z., "natural Eye Motion Synthesis by Modeling Gaze-Head Coupling", VR'09 Proceedings of the 2009 IEEE Virtual Reality Conference, pp.143-150, 2009

[Man11a] Mancini, M., Castellano, G., and Peters, C. , "Evaluating the Communication of Emotion via Expressive Gesture Copying Behaviour in an Embodied Humanoid Agent", Affective Computing and Intelligent Interaction Lecture Notes in Computer ScienceVolume 6974, pp.215-224, 2011

[Mar04a] Martinez-Conde, S., Stephen, L., and Hubel, D. H., "The role of fixational eye movements in visual perception", Nature Reviews Neuroscience 5, pp.229-240, 2004

[Mas07a] Masuko, S., and Hoshino, J., "Head-eye animation corresponding to a conversation for CG characters", Computer Graphics Forum, Journal of the European Association for Computer Graphics, vol.26, no.3, pp.303-311, 2007

[Mat03a] Mathews, A., Fox, E., Yield, J. and Calder, A., "The face of fear:Effects of Eye Gaze and Emotion on Visual Attention", Visual Cognition, 10:7, pp.823-835, 2003

[Sha05a] Shao, W., and Terzopoulos, D., "Autonomous pedestrians.", In Proceedings of the 2005 ACM SIGGRAPH/Eurographics symposium on Computer animation, pp.19-28, 2005

[Pel03a] Pelachaud, C., and Bilvi, M., "Modeling Gaze Behavior for Conversational Agents", Intelligent Virtual Agents, Springer, pp.93-100, 2003

[Wan02a] Wang, J. G., and Sung, E., "Study on Eye Gaze Estimation", IEEE Transaction on Systems,Man and Cybernetics-Part B: Cybernetics, vol.32 issue 3, pp.332-350, 2002

[Yeo12a] Yeo, S. H., Lesmana, M., Neog, D. R., and Pai, D. K., "Eyecatch: Simulating Visuomotor Coordination for Object Interception", ACM Transactions on Graphics, vol.31 issue 4, no.42, July 2012

[Zhe90a] Zheng, Y., F. and Shen, J., "Gait synthesis for the SD-2 biped robot to climb sloping surface," IEEE Trans. Robot. Automat., vol. 6, pp.86-96, 1990