Ballumiere: Real-Time Tracking and Projection for High-Speed Moving Balls

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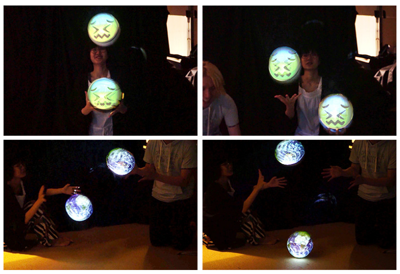

Figure 1. Projection to balls thrown in the air and bouncing at a floor.

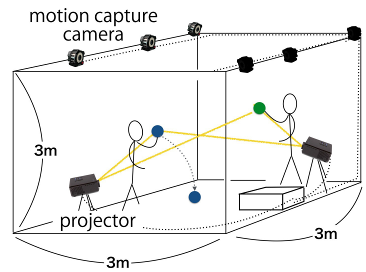

Figure 2. System overview.

ABSTRACT
Projection onto moving objects has a serious slipping problem due to delay between tracking and projection. We propose a new method to overcome the delay problem, and we succeed in increasing the accuracy of projection. We present Ballumiere as a demo for projection to volleyballs and juggling balls.

CCS Concepts
•Human-centered computing → Mixed / augmented reality; •Computing methodologies → *Tracking;*

Author Keywords
Dynamic projection mapping; prediction; tracking

INTRODUCTION
Recently projection mapping has attracted much attention. For example, Shader Lamps [4] enables to render computer graphics to real objects in three-dimensional space using projectors. However, almost all projection mapping techniques only allow projecting to static objects or projection targets that move slowly. To explore high quality experience by projection mapping, technology for projection onto moving objects is required. Lumipen [3] tracks and projects to a small object in real time using a high-speed vision sensor and a projector combination using a high-speed optical gaze controller. This system successfully projects to a quickly moving object, but only allows for one object to be a projection target because its optical axis of the vision sensors and the projector must be the same. Knibbe et al. [1] proposed the prediction method of using Kalman filter and a memory look up model with a Kinect camera. Lumospheres [2] can track balls and project images on them in real time using motion capture cameras and standard off the shelf projectors. This work overcomes the problem of the latency between tracking and projection by predicting the position of a ball using Kalman filter and kinetic model combination. However, they still have the problem of low projection accuracy when the movement speed of a ball changes quickly. To address this issue, we present a new method, the 3 frame prediction model, and switching prediction models according to motion of balls, and we succeed in minimizing the projection slipping (Figure 1).

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TECHNOLOGY
Figure 2 illustrates the overview of our system. The system consists of six cameras, two (or more) projectors and a PC for calculating prediction of balls's coordinates and also for rendering images. To capture the position of the ball, we used six motion tracking cameras (OptiTrack S250e) with 120 fps to track balls wrapped with retroreflective sheets. The three-dimensional position of the ball is computed immediately by the motion tracking system and is sent to the PC for calculation of appropriate image rendering considering the viewing angle from each projector.

Prediction
Since there is latency in the cameras, PCs, and projectors, the position of the ball captured by the camera is different from the position to be projected to. Some existing works overcome this issue with only Kalman filter, however they still have a problem with the projection

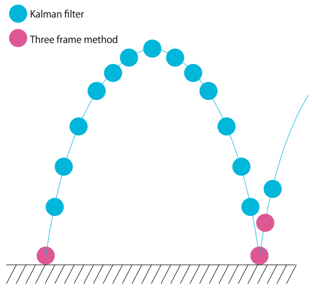

Figure 3. Adaptive model switching.

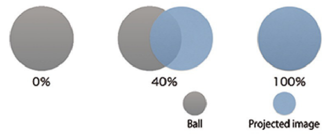

Figure 4. Projection accuracy examples.

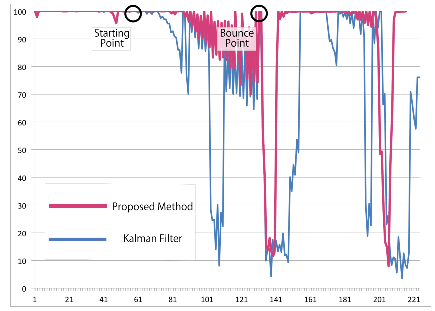

Figure 5. Comparison between Kalman filter and our proposed approach.

slipping when the ball's speed changes suddenly, for example when it is caught. To address this problem, we switch between Kalman filter and the 3 frame feedback prediction model (Figure 3) and succeed in minimizing the projection slipping.

We design the 3 frame feedback model to overcome the projection slipping occurring in existing research. Exp.1 shows predicted position of a ball in a projector space P_n at frame n.

$$P_n = p_n + Q_n R_n \tag{1}$$

$$Q_n = \alpha_1 d_n + \alpha_2 (d_n - d_{n-1}) \tag{2}$$

$$R_n = \begin{cases} |d_n| & (|d_n| < 0.001) \\ 1 & (|d_n| >= 0.001) \end{cases} \tag{3}$$

p_n is the current position of a ball captured by cameras, α is a correction coefficient for delay occurring at cameras, projectors and program, and d_n is the distance between the positions at present and at 1 frame before. There is the error component for acceleration because this system calculates acceleration by using data from motion capture cameras. Weighting terms of the equation with α works to minimize the effect of errors. P_n, predicted position, is corrected by Q_n, a function of d_n for a correction term of velocity and $d_n - d_{n-1}$ for that of acceleration, and R_n, a function for weighting by distance. Weighting by R_n(Exp.3) reduces projection slipping time at points where movement speed changes.

To improve prediction accuracy, we switch prediction models when movement speed of a ball changes. We estimate the condition of ball motion by y-axis acceleration and use Kalman filter under the influence of gravity and 3 frame feedback model under other conditions.

Evaluation

In the evaluation experiment, a ball is dropped from 135cm height with zero y-axis (vertical) initial velocity. Video is captured by a camera(120fps) beside a projector that projects an image onto a ball, and we calculate the accuracy of projection with Exp.4 each frame.

$$\text{Accuracy}[\%] = \frac{\text{image projected area[pixel]}}{\text{projection target area[pixel]}} \times 100 \tag{4}$$

Figure 4 shows how the projection efficiency measures a projected image. The projection efficiency of the left ball which nothing is projected on is 0%, that of the middle ball whose projection is slipped by its radius is 40% and that of the right ball which the same size image is projected on perfectly is 100%. We assess our proposed method of the combination of Kalman filter and 3 frame feedback model. We also evaluate no prediction model, Kalman filter with kinetic model and 3 frame feedback model for comparison. The average projection accuracies are 51.89[%] with no prediction model, 70.26[%] with Kalman filter and kinetic model, 86.08[%] with 3 frame feedback model and 89.79[%] with the combination of Kalman filter and 3 frame feedback model. Figure 5 shows comparison of the accuracy of "Kalman filter prediction model" and our proposed method. Especially at the first points of ball moving and just after bouncing points, our new model achieves high ratio of accuracy. It is because projections can soon back to the correct position with 3 frame feedback model.

CONCLUSION

In this paper, we proposed the combination of Kalman filter and 3 frame feedback model as a new prediction model for tracking and projection onto flying balls in real time. The results of our evaluation experiments support our approach being better than the previous Kalman filter model. Our results get 89.79%, a high projection accuracy, on a moving and bouncing ball and we increase it by 19.35% from our previous model.

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