

Projector-Camera Guided Fast Environment Restoration of a Biofeedback System for Rehabilitation

Yufei Liu and Gang Qian
Arts, Media and Engineering Program and
Department of Electrical Engineering
Arizona State University
{yufei.liu, gang.qian}@asu.edu

1. Introduction

This paper deals with the issue of fast and accurate physical environment restoration in a real time biofeedback system for stroke patient rehabilitation. The biofeedback system provides an interactive multimodal environment for patients to practice functional therapeutic reaching and grasping tasks, while receiving different types of feedback which indicate measures of performances and information for subsequent movements. The development of such a system will reduce rehabilitation time, promote more extensive recovery and alleviate rehabilitation monotony.

One key issue in the application of biofeedback system is that for a consecutive period an individual patient needs to practice tasks in a fixed physical environment with respect to the working volume. Here the physical environment includes: 1. the horizontal position of the chair on which the patient sits and the table with which the patient supports his/her arms, 2. the height of the table and the chair which are vertically adjustable. The reason for the necessity of environment restoration is apparent: only in the same environment can a patient gain consistent physical functions therapy. For example, the height of the table, to a large extent, affects how much patient support their arms and the way their arms move.

Different patients have different environment preferences. Even the same individual may have multiple preferences due to their rehabilitation progression. Each time a patient participates in therapy, a proper environment should be restored for him or her. All of these aspects make a fast, accurate and convenient approach for environment recording and restoration crucial.

In recent years, projector-camera systems have been used in a wide variety of applications such as multi-projector display walls, keystone correction and 3D reconstruction. In our approach all the cameras are calibrated beforehand and are used for a full calibration of the projector. We use motion capture cameras to record the appropriate physical environment for a patient. Corresponding projected images are generated to guide the restoration of the environment.

2. Propose Approach

There are two sets of cameras in the environment restoration system: 1. Six Eagle infrared motion capture cameras which run at 100 frames per second (fps) and can track 3D position of reflective markers. 2. Three synchronized video cameras running at 30fps. The cameras are mounted in a circle around the working volume with a mean distance 3.5m from the volume center. The projector is placed horizontally, 5m from the ground, and is assumed to be fixed with respect to the ground. A mirror is placed in front of the projector to redirect the projection downwards.

2.1. System Calibration

To calibrate the motion capture cameras we follow the standard calibration procedure provided by the Motion Analysis Corporation. For calibration of the three video cameras we use Svoboda's multi-camera self-calibration approach. The calibration is done by waving a laser pointer in the working volume. Lens distortion of video cameras is also computed. The world coordinate system of video cameras is aligned to that of motion capture cameras.

For projector calibration we utilized self-identifying bi-tonal ARTag patterns. In prior work Fiala [1] used the 2D tags to find out homographies between display surface and projectors to create a seamless combined image. ARTag is a marker system that contains 2002 planar patterns. Each pattern corresponds to a unique ID number.

We project ARTag images onto a flat rigid plate with a specific orientation and capture the plate by video cameras from three views. The 3D positions of the tags on the plate can be reconstructed according to the image correspondences. Ideally the reconstructed tags should lie in a plane. However, due to noise they are in fact distributed in a three dimensional space. Principal Components Analysis is used to solve this plane fitting problem. A 2D coordinate system is constructed by choosing the first two orthogonal principal axes of all of the tags. Then the coordinates of all the tags are updated in this 2D system.

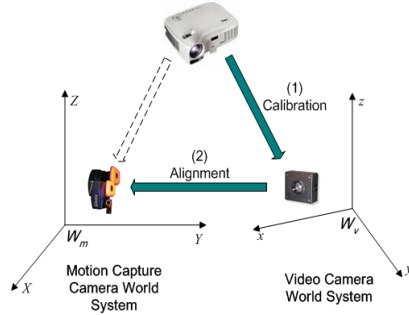


Figure 1: The 2-step calibration of projector in the world system of motion capture cameras.

We can obtain several homographies between the plate and the projector by changing the orientation of the plate. Seeing the projector as an inverse camera, there are many techniques available for calibration. The calibration technique proposed by Zhang is used to estimate the projection matrix of the projector. Bundle adjustment is then applied to for a refined calibration. In this way we complete the projector calibration. The projector is then aligned with the motion camera system as show in Fig. 1.

2.2. Recording of the Environment

Once the patient finds a suitable configuration of the environment, we start the two-step recording. (1) Attach four infrared reflective tape markers on four corners of the table respectively and record their 3D positions using the motion capture camera system. This step corresponds to table height restoration. (2) Drop the table down to the lowest point and record the 3D positions of the four markers again. This step corresponds to restoring the table's horizontal position on the ground.

2.3. Environment Restoration

Similar to the recording of the environment, the restoration is also a 2-step process. (1) Restoration of the horizontal position of the table on the ground. We drop the table down to the lowest point and project a synthetic image containing black background and four bright blobs. The four bright blobs are generated according to the 3D marker positions in Step.2 of recording. If we consider the projector as an inverse camera, then a bright blob is the image of a corresponding marker on one corner through the imaging of the projector. Therefore the bright blobs coincide with table corners only if the table's horizontal position is restored. (2) Restoration of the table's height. Another image with four bright blobs is generated according to the 3D marker positions in Step.1 of recording. We move the table until its corners coincide with the blobs. To make it easier to operate, in the projected image we connect two adjacent blobs with bright lines to form a bright rectangle which is easier to observe than blobs.

In order to make the restoration more interactive, we track the four tape markers on table corners using motion capture cameras and project feedback containing both patterns and texts onto the table in real time shown in Fig. 2. The patterns such as arrows indicate in what directions should we move the table and the texts indicate how far to go. When the restoration is completed, a check pattern is projected. Since sometimes the tape markers can be occluded from cameras by people while moving the table, in these cases we project an alert pattern to remind people.



Figure 2: Left: a bright rectangle formed by the 4 bright blobs. Right: real time visual feedback projected on the table. The arrows indicate where to move the table. The texts indicate how much to move. For example: Move FORWARD 28mm, as shown at the bottom in the right figure.

An average error of 3mm is achieved for horizontal restoration and 2mm for height restoration of the table. As for the chair we follow the same method and small restoration error (less than 4mm) is achieved.

3. Conclusion

In this paper we have developed an application for a new projector-camera system to be used in the environment restoration of a biofeedback system intended for stroke patient rehabilitation. The conjunction of the projector and highly accurate motion capture cameras has greatly expedited the environment recording and restoration processes, especially considering the large number of patients involved. As experimental results have shown, accurate restoration of the environment is achieved approximately one minute.

This projector-camera system can be easily extended to other applications such as human-computer interaction in the biofeedback system. For example, some meaningful patterns can be projected according to patients' hand trajectory or movement pattern computed from the motion capture system. This feedback can serve as either a cognitive stimuli to guide them where and how to move, or it can serve as an evaluation of their performances. This system makes the therapy more functional, purposeful and engaging.

4. References

- [1] M. Fiala, "Automatic Projector Calibration Using Self-Identifying Patterns," in *CVPR*, 2005.