Camera Driven Robotic Light Source Positioning

Felipe Hernández-Rodríguez, Gustavo Arechavaleta and Mario Castelán*

Centro de Investigación y de Estudios Avanzados del I.P.N.
Grupo de Robótica y Manufactura Avanzada,
Ramos Arizpe, Coahuila, 25900, México

Abstract. We address the problem of automatic light source positioning using a robotic device. The task is guided by a fixed camera which measures pixel luminance information about the observed object. The movable light source is attached to the robot's end-effector. We propose a motion planning strategy to find the sequence of feasible positions and orientations of the light source while satisfying the robot postures and the environment constraints. First, our strategy determine the set of optimal spatial locations of the light source by minimizing the difference with a reference measure of luminance. Then, for each valid configuration an iterative inverse kinematics solver calculates the pose for robot that satisfies environment constraints. Preliminar results are shown using a simulation tool. Potential applications of this work may be situated within the field of Computer Vision, i.e., database gathering with varying illumination conditions, illumination correction in imaging and 3D reconstruction using photometric stereo.

Key words: Light source positioning, Image acquisition, Robot motion planning.

1 Introduction

Computer Vision and Imaging is an important field with potential applications in surveillance, medicine, animation and robotics. The acquisition of accurate data describing the appearance of objects is therefore of great importance in this field. To this end, databases are generated which best describe relevant image features such as differences in pose and illumination. The most common way to acquire this information is through the gathering of images to generate a database. Normally, in the database acquisition process, either the camera or the light sources remain fixed to certain locations. This assumes that the luminance properties of the different objects observed by the camera are exactly the same. Unfortunately, this assumption breaks for almost every object, since too many factors such as surface shape, albedo, inter-reflections, ambient light, view point, etc., have to be considered here.

In this work, the aim is to develop a novel imaging robotic acquisition framework that is able to move a light source so as to compel the requirements of a

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fixed camera. These requirements may be any constraints imposed on the captured image under different light source directions, for example, the distribution function of the luminance (histogram), edge detection or image distortion quality measures.

The document is organized as follows: in Section 2, previous work will be described; in Section 3, the formal proposal of the robotic framework will be explained; in Section 4, preliminary results minimizing the difference with a reference histogram will be shown in order to give an application example; finally, in Section 5 conclusions and future work will be outlined.

2 Previous work

Examples of databases observing changes in illumination and pose can be found in the field of face analysis. The Yale B database [2] was created to study human faces for the purposes of 3D reconstruction and recognition under changes in illumination and pose. Images of subjects were taken using a meshed sphere with attached light sources to each of the vertex of the sphere. Different combinations of light sources were synchronized with fixed cameras in order to record illumination changes. The Carnegie Mellon University pose, illumination and expression database (CMU Pie)[4] also includes changes in facial expression and illumination changes were simulated using a projector.

As far as the area of robotics is concerned, Collewet and Marchand [1, 3] propose to use a robotic arm to achieve a visual control based on a reference photograph. This approach seeks to positioning the robot's end-effector by minimizing the difference between a reference photograph and an observed photograph within the field of view of a camera. Either the light source or the camera may be mounted on the end-effector of the robot. Unlike the traditional visual servo control which uses points and lines and other basic features in an image to position the robot, Collewet and Marchand's work introduce the intensities of all the pixels to minimize an energy function based on luminance and contrast. Their attempts are amongst the firsts to include photometric features into the visual control laws. A limitation of their work is that it targets photographs (projections on a plane) rather than real objects in 3D, therefore obviating the reflectance implications and interactions of the 3D world and the light sources.

3 Light source positioning

Here we describe our motion planning strategy to automatically solve the light source positioning problem. First, we compute the optimal set $r \in \mathbb{R}^m$ of light source locations by minimizing the difference between the luminance properties of the actual scene and a given reference luminance. It is important to recall that the light direction can be defined by two parameters on $\mathbb{S}^2$, azimuth and zenith. We assume that the observed object is located at the center of the sphere. After the set of locations is found, we solve a path planning problem to link the sequence of light source configurations. It is well known that six independent parameters, $r = (x, y, z, \theta, \phi, \psi)$, are required to define a valid configuration of a rigid body (i.e., the light source) that represents a spatial location in the Workspace. Thus, the topology of the search space is represented by a 6-dimensional manifold $SE(3)$.

Because the valid positions of the light source are defined on the surface of a sphere, $\mathbb{S}^2 \subset \mathbb{R}^3$, the following holonomic constraint of the form $h_1(r) = 0$ is defined ($x^2 + y^2 + z^2 - b^2 = 0$), where b is the radius of the sphere. We define two additional constraints, $h_2(r) = 0$ and $h_3(r) = 0$, for restricting the light direction towards the object. To determine such constraints we applied the following procedure. First, we construct the matrix $R = [\boldsymbol{c}\ \ \boldsymbol{d}\ \ \boldsymbol{b}] \in SO(3)$ where $\boldsymbol{c} = \boldsymbol{a} \times \boldsymbol{b}$, $\boldsymbol{a}$ represents the position of the light source w.r.t. the Workspace reference frame, $\boldsymbol{b}$ is the normal vector on $\mathbb{S}^2$ pointing to the object, $\boldsymbol{d} = \boldsymbol{b} \times \boldsymbol{c}$. As a consequence, vectors $\boldsymbol{c}$ and $\boldsymbol{d}$ form a tangent plane at each point on $\mathbb{S}^2$. Based on the plane equation, h_2 and h_3 are defined by $b_x\,(c_x - x) + b_y\,(c_y - y) + b_z\,(c_z - z) = 0$ and $b_x\,(d_x - x) + b_y\,(d_y - y) + b_z\,(d_z - z) = 0$ respectively. Thus, a 3-dimensional unconstrained manifold represents the feasible search space for the light source path planning problem. We link a pair of points on $\mathbb{S}^2$ by great circles (i.e. the shortest paths on $\mathbb{S}^2$) and we find the orientation components along the path using R. After a path is computed, which is composed by a set of valid positions and orientations of the robot's end-effector, then we apply an IK solver to find the corresponding robot posture $q = [q_1, q_2, ...q_n] \in \mathbb{R}^n$. We solve the so-called generalized IK problem

$$\delta q = J^{\#}\delta r + (I_n - J^{\#}J)\gamma$$

where $J^{\#}$ is the pseudoinverse of the task Jacobian matrix J, n is the dimension of q that represents the number of degrees of freedom (DOF) of the robot, I_n the n-dimensional identity matrix and γ an arbitrary vector to optimize. If $n = m$ then the solution of the IK is reduced to $\delta q = J^{-1}\delta r$. The advantage of the generalized IK solver for a light source positioning problem is the possibility to perform other tasks simultaneously (e.g. avoiding collisions, posture singularities, attaching a movable camera to the robot, etc.) by using the remaining DOF of the robot.

4 Preliminary results

We use the difference with a reference histogram to determine the position of the light source (end-efector of the robot). The movements of the robot are bound to lie on a 3D sphere. The reference histogram is fixed to a 10^o elevation angle (zenith). Along equally spaced azimuth angles, ranging from 0^o to 360^o, histograms are generated while the zenith angle is moved away from the center of the sphere. A measure of error with the reference image is then recorded. Finally, the points that minimize the error are set as landmarks to be followed by a path planner. In the simulation, the calculation of the different image histograms is realized doing a lambertian renderization of a known 3D model of a face (taken from a subject of the Yale B database) with variable albedo. There is an interest in following trajectories lying on the surface of a sphere in order to isolate direction of the light source from intensity. The effect of variable intensity can be added by controlling the intensity of the light using a power regulating system. In Figure 1 the projection on the plane of the light source positions to be followed by the robot are shown as circled landmarks.

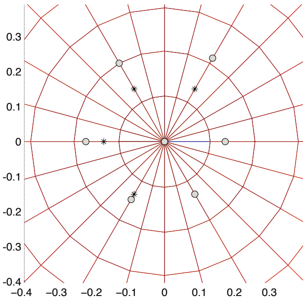

Fig. 1. Projection on the plane of the light source positions to be followed by the robot (left). The star landmarks represent a fixed 10^o azimuth angle trajectory. The circled landmarks are the obtained using the histogram based error.

5 Perspectives

A natural extension of this work is the experimental validation of the proposed strategy. Our experimental protocol will consider that the light source is going to be manipulated by a redundant robotic platform. This will allow the the construction of real databases of objects with illumination changes in a non structured environment. We expect that our strategy can be employed to automatically generate illumination changes with robot motions that permit the 3D reconstruction of objects with the photometric stereo method.

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