ASSIGNMENT 3

ROB521: Mobile Robotics and Perception

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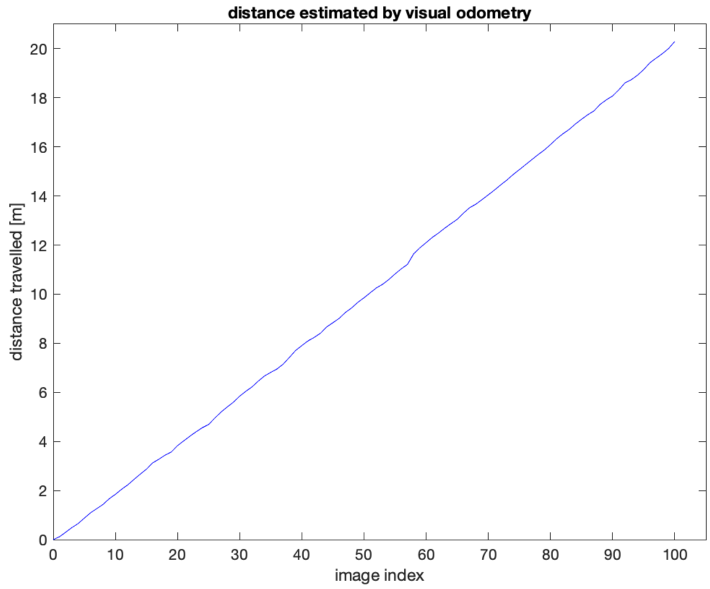
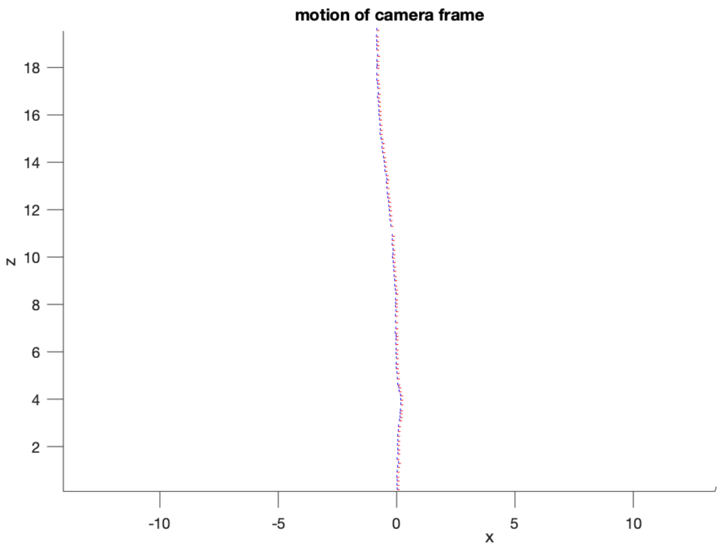
March 28, 2020

1 Stereo Visual Odometry Results

In this project, we use stereo visual odometry to estimate the motion of a mobile robot, using a real image dataset. The resulting estimations are show below:



(a) Distance travelled.



(b) Motion.

Figure 1: Motion estimation with stereo visual odometry.

2 Discussion

Figure 1a shows the distance travelled by the robot, which linearly increases with time, indicating that the robot was likely traveling along a certain orientation at a constant speed. There are indeed some squiggles, probably as a result of the bumpy ground. However, the line has no discontinuity remains straight in general.

Figure 1b shows the motion of camera frame and robot. There several aspects worth discussing:

- The robot travels along z-direction in almost a straight path, which is very consistent to Figure 1a.
- The blue and red represent the camera and robot, respectively. They are very close together and remains this way. This is also expected, as the camera and robot are supposed to be fixed together.
- There are a few discontinuities (e.g., at $z = 2, 4, 8, 11$). They can be caused by the following
  - RANSAC might have eliminated too many features in these frames that the matching was affected
  - There could simply be no good feature at all in these frames - for example, when the robot is bumping through an obstacle, the camera could be shaking so much that the features are blurry or skewed.

Appendix: Source Code

```
% ======
% ass3.m
% ======
%
% This assignment will introduce you to the idea of estimating the motion
% of a mobile robot using stereo visual odometry.  It uses a real image
% dataset gathered in the Canadian High Arctic in 2009.
%
% There is only one question to complete (10):
%
%    Question: code the least-squares motion solution based on two
%    pointclouds
%
% Fill in the required sections of this script with your code, run it to
% generate the requested plots, then paste the plots into a short report
% that includes a few comments about what you've observed.  Append your
% version of this script to the report.  Hand in the report as a PDF file.
%
% requires: basic Matlab, 'matches.mat', directory of images
%
% T D Barfoot, February 2016
%

function vo()

    clear all;

    % watch the included video,
    load matches.mat matches;
    imax = size(matches,2);

    % stereo camera parameters
    b = 0.239977002;    % baseline [m]
    f = 387.599884033;  % focal length [pixel]
    cu = 253.755615234; % horiz image centre [pixel]
    cv = 185.114852905; % vert image centre [pixel]

    % global transform to camera (starts as identity)
    T = eye(4);

    % distance travelled (starts at zero)
    d(1) = sqrt(T(1:3,4)'*T(1:3,4));

    % initialize some figures
    h1 = figure(1); clf;
    h2 = figure(2); clf;

```

```
% loop over the stereo pairs
for i=1:imax

    i

    % get number of feature matches
    npoints = size( matches{i}, 1);

    % use the inverse stereo camera model to turn the first stereo pair into a pointcloud
    uL1 = matches{i}(:,1);
    vL1 = matches{i}(:,2);
    uR1 = matches{i}(:,3);
    vR1 = matches{i}(:,4);
    p1 = [ b*( 0.5*(uL1 + uR1) - cu ) ./ (uL1 - uR1) ...
           b*( 0.5*(vL1 + vR1) - cv ) ./ (uL1 - uR1) ...
           b*f*ones(size(uL1)) ./ (uL1 - uR1) ]';

    % use the inverse stereo camera model to turn the first stereo pair into a pointcloud
    uL2 = matches{i}(:,5);
    vL2 = matches{i}(:,6);
    uR2 = matches{i}(:,7);
    vR2 = matches{i}(:,8);
    p2 = [ b*( 0.5*(uL2 + uR2) - cu ) ./ (uL2 - uR2) ...
           b*( 0.5*(vL2 + vR2) - cv ) ./ (uL2 - uR2) ...
           b*f*ones(size(uL2)) ./ (uL2 - uR2) ]';

    % RANSAC
    maxinliers = 0;
    bestinliers = [];
    p1inliers = [];
    p2inliers = [];
    itermax = 1000;
    iter = 0;
    while iter < itermax && maxinliers < 50

        iter = iter + 1;

        % shuffle the points into a random order
        pointorder = randperm(npoints);

        % use the first 3 points to propose a motion for the camera
        [C,r] = compute_motion( p1(:,pointorder(1:3)), p2(:,pointorder(1:3)) );

        % compute the Euclidean error on all points and threshold to
        % count inliers
        e = p2 - C*(p1 - r*ones(1,npoints));
```

```
            reproj = sum(e.*e,1);
            inliers = find(reproj < 0.01);
            ninliers = size(inliers,2);
            if ninliers > maxinliers
                maxinliers = ninliers;
                bestinliers = inliers;
                p1inliers = p1(:,inliers);
                p2inliers = p2(:,inliers);
            end

    end

    % recompute the incremental motion using all the inliers from the
    % best motion hypothesis
    [C,r] = compute_motion(p1inliers,p2inliers);

    % update global transform
    T = [ C -C*r; 0 0 0 1]*T;

    % update distance travelled
    d(i+1) = sqrt(T(1:3,4)'*T(1:3,4));

    % this figure shows the feature tracks that were identified as
    % inliers (green) and outliers (red)
    figure(h1)
    clf;
    IL1 = imread(['images/grey-rectified-left-' num2str(i,'%06i') '.pgm'], 'pgm');
    imshow(IL1);
    hold on;
    for k=1:npoints
       set(plot( [uL1(k) uL2(k)], [vL1(k) vL2(k)], 'r-' ), 'LineWidth', 2);
    end
    for k=1:maxinliers
       set(plot( [uL1(bestinliers(k)) uL2(bestinliers(k))], [vL1(bestinliers(k)) vL2(bestinliers(k))], 'g-' ), 'LineWidth', 2);
    end

    % this figure plots the camera reference frame as it moves through
    % the world - try rotating in 3D to see the full motion
    figure(h2)
    hold on;
    startaxis = [0.1 0 0 0; 0 0.1 0 0; 0 0 0.1 0; 1 1 1 1];
    curraxis = inv(T)*startaxis;
    plot3( [curraxis(1,1) curraxis(1,4)], [curraxis(2,1) curraxis(2,4)], [curraxis(3,1) curraxis(3,4)], 'r-' );
    plot3( [curraxis(1,2) curraxis(1,4)], [curraxis(2,2) curraxis(2,4)], [curraxis(3,2) curraxis(3,4)], 'g-' );
    plot3( [curraxis(1,3) curraxis(1,4)], [curraxis(2,3) curraxis(2,4)], [
```

```
    curraxis(3,3) curraxis(3,4)], 'b-' );
        axis equal;

        pause(0.01);
    end

    % finish off this figure
    figure(h2);
    xlabel('x'); ylabel('y'); zlabel('z');
    title('motion of camera frame');
    print -dpng ass3_motion.png

    % this figure simply looks at the total distance travelled vs. image
    % index
    figure(3);
    clf;
    plot(linspace(0,imax,imax+1),d,'b-')
    axis([0 105 0 21])
    xlabel('image index');
    ylabel('distance travelled [m]');
    title('distance estimated by visual odometry');
    print -dpng ass3_distance.png

end

% this is the core function that computes motion from two pointclouds
function [C, r] = compute_motion( p1, p2 )

    % ------insert your motion-from-two-pointclouds algorithm here------

    n = size(p1, 2);

    % If there's no point or different number of points
    if (n == 0) || (n ~= size(p2, 2))
        C = eye(3);     % temporary to make script run
      r = zeros(3,1); % temporary to make script run
    else
        % Centriod of points
        c1 = mean(p1, 2);
        c2 = mean(p2, 2);

        % Scalar-Weighted Point Cloud Alignment's outer product matrix
        diff1 = bsxfun(@minus, p1, c1);
        diff2 = bsxfun(@minus, p2, c2);
        W = diff2 * diff1' / n;

        % SVD decomposition
        [V,~,U] = svd(W);

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```
        % Compose rotation and translation from SVD
        M = [1 0 0; 0 1 0; 0 0 det(U)*det(V)];
        C = V * M * U';
        r = -C'*c2 + c1;
    end

    % ------end of your motion-from-two-pointclouds algorithm-------

end
```