DIPOLE LATTICE

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Upscaling a nano-structure

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May-July, 2013

Atul Singh Arora: *Dipole Lattice,* Upscaling a nano-structure,

Every honest researcher I know admits he's just a professional amateur. He's doing whatever he's doing for the first time. That makes him an amateur. He has sense enough to know that he's going to have a lot of trouble, so that makes him a professional.

— Charles F. Kettering (1876-1958) (Holder of 186 patents)

ACKNOWLEDGEMENTS

I thank Dr. Ravi Mehrotra for, well conceiving the experiment and guiding me through the process of its realization.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

LISTINGS

ACRONYMS

1 PROLOGUE

Atoms and molecules are far too small to be observable as individual entities, with our eyes alone. Scientists have come a long way at understanding *their* world. It has been attempted to recreate a specific micro-structure, at a scale where we can directly observe it.

The configuration we've studied here, is that of a Magnetic Dipole Lattice, viz. Magnetic Dipoles that can only rotate about their axis, placed on a grid. Their physics by itself is rather interesting and can be simulated to observe the dynamics. The experiment is expected to show the same dynamics, that of the microscopic world, only directly observable.

1.1 PRIOR ART

TODO: Complete this part after understanding the physics and simulations on the system.

1.2 EXPERIMENTAL SETUP

The upscale version consists of Physical Magnetic Dipoles, that rest on near zero friction spots on a grid. A camera sits on top, with all the dipoles in its field of view. The Lattice Analyser takes the input from the camera and simulates the given temperature through a hardware unit and the coils attached to each dipole. It is that simple.

For implementation details, you may read the following sections.

1.2.1 *The Dipole*

According to the current design (as of May 19, 2013), the Magnetic Dipole is built off of two small cylindrical rare earth magnets, attached to a needle, with their flat face's surface normal perpendicular to the axis of the needle. The needle rests in an assembly that keeps it upright and nearly free of friction. Each dipole further has a circular disc on top, with its centre passing through that of the dipole. The disc has a pattern printed, designed to find its angular position using a camera. Further, the dipole assembly also has two coils along an axis perpendicular to the needle.

1.2.2 *Lattice Analyser*

This is the application that

1. records the dynamics of the system
2. calculates the required field strength of each electromagnet

using a webcam and computer vision techniques. The results of the latter part depend on the temperature that is to be simulated; temperature is not maintained by providing heat, but instead by providing a certain distribution of speeds to the dipoles.

1.2.3 *Temperature*

This is the hardware unit, (will be built around an ATmega 16) that provides the coils with the current as calculated by the Lattice Analyser (using a USB interface).

2 WATCH IT GROW

2.1 SENTIMENTAL INTRODUCTION

Science often seems like a blackbox that relates observables. Even more often, it is rather convenient to lose touch of observables altogether, and wander in the blackbox. Performing an experiment, gets one closer to nature, to the roots of the subject.[1]

2.2 THE JOURNEY

This experiment wasn't started from scratch. My guide, Dr. Ravi Mehrotra, had already worked with a team and created the Dipoles as described earlier. The team had also worked on the image detection algorithms, but their work wasn't usable.

There were three tasks at hand, of which one had been

2.2.1 *Time Line*

Listed below is the event log, which has the progress as and when it was made.

Time Line

```
* May 17, Friday: The algorithm was successfully completed to
    measure 360 degrees. PLUS, completed the frame recording,
    identification of each dipole as unique and dumping the data
    out in file AND its testing with uniform motion which it
    passed with flying colours (which is to say in the visible
    range!, because proper standard deviation tests haven't quite
     been done yet) The vision part of the anlyser is almost done
    .

* May 16, Thursday: Working on dipole detection. The algorithm
    has started to work partially. It still does a mod 180
    detection.

* May 15, Wednesday: The magnetic lifting worked, but friction
    reduction failed. Rather interestingly the dipole would align
     to the suspension magnet's field. Plus, today the spot
    recognition algorithm was finalized and it seemd to be
    perfect.
```

1 This section can be skipped, without any loss of continuity.

```
* May 14, Tuesday: Trying to get the webcam to work, eventually
    acceded to installing everything on a desktop machine. Worked
     on reducing the friction further

* May 13, Monday: Completed the proof of concept version of the
    latticeAnlyser. Tomorrow we plan to print the coloured ovals
    and test

** May 11 and 12, Saturday and Sunday: Read the opencv tutorials
    when the algorithms started appearing and fitting the bill!

* May 10, Friday: Continued with the setup, finetuning,
    installing other applications, making a documentation
    alongside for better support next time, added a shared folder
     between windows and linux

* May 9, Thursday: Managed to get a few things up and running,
    still setting up ubuntu to run with hardware acceleration,
    failed at trying to get the webcam to work, installed the
    build tools, opencv etc.

* May 8, Wednesday: Met with Dr. X (forgot the name of the person
     at NPL I'm working with) and concluded OpenCV and linux are
    what I'll use. Initiated the downloading of required
    applications, including virtual box and an ubuntu image
```

2.2.2 *Construction of the Lattice Analyser*

The lattice analyser has come a long way.

latticeAnalyser.cpp

```
/*
  filename: latticeAnalyser.cpp
  description: This is the main application which analyses the
      lattice and
                  1. controls 'temperature'
                  2. records dipole position (thus angular
                      velocity) as a function of time
  baby steps (TM):
    1. Proof of concept stage
        a. Find a suitable algorithm
        b. Make the required modifications
            i. Add a colour filter
              Implement two colours [done]
              Add two sliders for adjusting tolerance [done, but
                  need to refresh something!]
              Add GUI for selecting the colours [done, but not a
                  gui so to speak]
              save settings [not doing it]
    2. Look at it grow!
```

```
        a. Enable screen cropping [done]
        b. Write an algorithm for ellipse to dipole conversion [
            completed]
        c. Save data for each frame using a circular array of
            sorts [done]
        d. Output the data perhaps in a text file  [done]
*/

#include "opencv2/highgui/highgui.hpp"
#include "opencv2/imgproc/imgproc.hpp"
#include <iostream>
#include <stdio.h>
#include <stdlib.h>
// #include <string.h>
// #include <array>

using namespace cv;
using namespace std;

Mat srcPreCrop; Mat src; Mat src_gray; Mat srcColorFilter; Mat
    src_process; Mat srcColorA; Mat srcColorB;
//for the cropping
int cropped = 0;
Point origin;
Rect selection;
bool selectRegion;

// Mat cimg;
Mat_<Vec3b> srcTemp = src;
int thresh = 100;
int max_thresh = 255;
int canny=100;
int centre=30;
int minMinorAxis=1, maxMajorAxis=30;
int mode=0;
float theta=3.14159;

//mode
//0 is screen select
//1 is colour select

RNG rng(12345);

//////////////DIPOLE DETECTION

class dipole
{
public:
  float angle,order; //angle is the angle, order gives a rough
      size of the dipole detected
  int x,y,id;  //centre, id tells where its mapped
  int e1,e2; //index number of ellipse
```

```
  static int count[2]; //double buffer
  static int current;
};

int dipole::count[2] = {0};
int dipole::current=0;

//Not using a dynamic array, doesn't matter for now
//TODO: Use a dynamic aray
// array<dipole,500> dipoles;
// array<dipole,500> lastDipoles;
#define DmaxDipoleCount 1000
dipole dipoles[2][DmaxDipoleCount];
// Colour read
// Point origin;



///////////////DIPOLE INFORMATION STORAGE IN RAM
bool dipoleRec=false;

class dipoleSkel
{
public:
    float angle;
    int x,y;
    float instAngularVelocity;
    bool detected;  //stores whether the dipole was detected at
        all
};

//This class is for storing dipole data of a given frame
class dipoleFrame
{
public:
  double time;   //time elapsed since the seed frame
  float order;  //gives the rough size of the dipoles
  vector<dipoleSkel> data;
};

// #define DframeBufferLen  5000
dipoleFrame seedDipole;
//NOTE: You have to fix the numbering problem right here.
vector <dipoleFrame> dipoleData;

#define DframeBufferLen 5000
////THIS IS FOR STORING IN FILE
FILE * pFile;
char fileName[50];


//////////////////////////////
```

```
// This is a colour filter for improving accuracy
  // 20, 28, 41 [dark]
  // TODO: Allow the user to select the colour
  Scalar colorB=Scalar(245,245,10);
  Scalar colorA=Scalar(10,245,245);
  int colorATol=30;
  int colorBTol=30;
//
  const char* source_window = "Source";
  const char* filter_window = "Color Filter";
  const char* settings_window="Settings";


//////////TIMING
  long t,tLast;
  double deltaT;
static void onMouse( int event, int x, int y, int, void* )
{
  if(mode==0)
  {
    if( selectRegion )
    {
        selection.x = MIN(x, origin.x);
        selection.y = MIN(y, origin.y);
        selection.width = std::abs(x - origin.x);
        selection.height = std::abs(y - origin.y);

        selection &= Rect(0, 0, src.cols, src.rows);
    }

    switch( event )
    {
    case CV_EVENT_LBUTTONDOWN:
        cropped=0;
        origin = Point(x,y);
        selection = Rect(x,y,0,0);
        selectRegion = true;
        break;
    case CV_EVENT_LBUTTONUP:
        cropped=0;
        selectRegion = false;
        if( selection.width > 0 && selection.height > 0 )
            cropped = -1;
        break;
    }
  }
  else if(mode==1)
  {
    switch( event )
    {
    case CV_EVENT_LBUTTONUP:
```

```
        cout<<x<<","<<y<<endl;
        colorA=Scalar(src.at<Vec3b>(x,y)[0],src.at<Vec3b>(x,y)
            [1],src.at<Vec3b>(x,y)[2]);
        cout<<"Color A's been changed to "<<endl<<colorA.val[0]<<
            endl<<colorA.val[1]<<endl<<colorA.val[2]<<endl;
        break;
    case CV_EVENT_RBUTTONUP:
        cout<<x<<","<<y<<endl;
        colorB=Scalar(src.at<Vec3b>(x,y)[0],src.at<Vec3b>(x,y)
            [1],src.at<Vec3b>(x,y)[2]);
        cout<<"Color B's been changed to "<<endl<<colorB.val[0]<<
            endl<<colorB.val[1]<<endl<<colorB.val[2]<<endl;
        break;
    }
  }
}



int process(VideoCapture& capture)
{

  for(;;)
  {


    {  //IMAGE CAPTURE and CROP
      capture>>srcPreCrop;
      tLast=t;
      // t=getTickCount()/getTickFrequency();   //This is give
          time in seconds
      t=getTickCount();
      deltaT=(t-tLast)/getTickFrequency();

      if(dipoleRec)
      {
        //if this is not the last frame, add a frame
        dipoleData.push_back(seedDipole);
        //This is to avoid overflows
        // if (dipoleData.size()>DframeBufferLen)
          // dipoleData.erase(dipoleData.begin());
        //for the last frame
        dipoleData[dipoleData.size()-1].time=dipoleData[
            dipoleData.size()-2].time+deltaT;
      }

      // long cfInit=dipoleData.size()-1;  //last frame

      // //test for current frame
      // if(dipoleData[cfInit].time!=t)
      // {
      //   //if this is not the last frame, add a frame
```

```
  //   dipoleData.push_back(seedDipole);
  //   //This is to avoid overflows
  //   if (dipoleData.size()>DframeBufferLen)
  //     dipoleData.erase(dipoleData.begin());
  //   //for the last frame
  //   cfInit=dipoleData.size()-1;
  //   dipoleData[cfInit].time=t;
  // }



  if(srcPreCrop.empty())
  {
    cout<<"Didn't get an image";
    break;
  }
  if(!cropped==0)
  {
    src=srcPreCrop(selection);
  }
  else
    src=srcPreCrop;
  imshow( source_window, srcPreCrop );
}

//////////////////////
{//COLOR FILTER
  //Input src, output src_gray
  Scalar lowerBound;
  Scalar upperBound;

  lowerBound = colorA-Scalar::all(colorATol);
  upperBound = colorA+Scalar::all(colorATol);
  // Now we want a mask for the these ranges
  inRange(src,lowerBound,upperBound, srcColorA);

  lowerBound = colorB-Scalar::all(colorBTol);
  upperBound = colorB+Scalar::all(colorBTol);
  // We do it for both the colours
  inRange(src,lowerBound,upperBound, srcColorB);

  // Now we create a combined filter for them
  addWeighted(srcColorA, 1, srcColorB, 1, 0, srcColorFilter);


  /// Convert image to gray
  cvtColor( src, src_process, COLOR_BGR2GRAY );

  /// Now keep only the required areas in the image
  // // // multiply(src_process,srcColorFilter,src_gray,1);
  src_gray=srcColorFilter.mul(src_process/255);
  // // // src_gray=srcColorFilter;
```

```
  // NOw blur it
  blur( src_gray, src_gray, Size(3,3) );

  imshow( filter_window, src_gray);
}

/////////////////////////////

// BLANK PROCESSING
// medianBlur( src, src, 5 );
// cvtColor( src, src_gray, COLOR_BGR2GRAY );

// // // blur( src_gray, src_gray, Size(3,3) );

/////////////////////////////
// This is contour Detection
/////////////////////////////////
Mat threshold_output;
vector<vector<Point> > contours;
vector<Vec4i> hierarchy;

/// Detect edges using Threshold
threshold( src_gray, threshold_output, thresh, 255,
    THRESH_BINARY );
/// Find contours
findContours( threshold_output, contours, hierarchy,
    RETR_TREE, CHAIN_APPROX_SIMPLE, Point(0, 0) );

/// Find the rotated rectangles and ellipses for each contour
vector<RotatedRect> minRect( contours.size() );
vector<RotatedRect> minEllipse( contours.size() );

for( size_t i = 0; i < contours.size(); i++ )
   { minRect[i] = minAreaRect( Mat(contours[i]) );
     if( contours[i].size() > 5 )
       { minEllipse[i] = fitEllipse( Mat(contours[i]) ); }
   }

for( size_t i = 0; i< minEllipse.size(); i++ )
   {
    //You can add aditional conditions to eliminate detected
        ellipses
    if(!(
      (minEllipse[i].size.height>minMinorAxis && minEllipse[i
          ].size.width>minMinorAxis)
      &&
      (minEllipse[i].size.height<maxMajorAxis && minEllipse[i
          ].size.width<maxMajorAxis)
      ))
    {
```

```
        // minEllipse[i]=RotatedRect(Point2f(0,0),Point2f(0,0)
            ,0);
        minEllipse.erase(minEllipse.begin()+i--);
      }
     }



//////////////////////////
//  Dipole Detection Algorithm
//////////////////////////
vector<bool> detected (minEllipse.size(),false);

int k = !(dipoles[0][0].current);
dipoles[0][0].current=k;
dipoles[0][0].count[k]=0;

// dipolesA[0].lastcount=0;
for (int i=0; i<minEllipse.size();i++)
{
  if(detected[i]==false)
  {
    for (int j=0; j<minEllipse.size();j++)
    {
      if((i!=j) && detected[j]==false)  //This is so that you
           don't test with yourself and with others that got
          paired
      {
          // if(abs(minEllipse[i].angle-minEllipse[j].angle)<
               15)  //if the orientation matches (less than 5
               degrees), then
          {
            //Find the distance between minEllipses

            Point differenceVector=Point(minEllipse[i].center
                .x - minEllipse[j].center.x, minEllipse[i].
                center.y - minEllipse[j].center.y);  //find
                the difference vector
            float distanceSquared=differenceVector.x*
                differenceVector.x + differenceVector.y*
                differenceVector.y; //find the distance
                squared

            //Find the major axis length
            float majorAxis=MAX( MAX(minEllipse[i].size.width
                , minEllipse[i].size.height) , MAX(minEllipse
                [j].size.width, minEllipse[j].size.height));
                //find the max dimension

            //The ratio is the ratio between the distance
                between the ellipse and the small circle and
                the length of the major axis
```

```
                float errorPlusOne = distanceSquared /
                    ((11.348/30)*(11.348/30)*majorAxis*majorAxis)
                     ; //now to compare, just divide and see if
                    it's close enough to one

                if (errorPlusOne>0.5 && errorPlusOne<2)  //if the
                     error is small enough, then its a match
                {
                    //This is to ensure these don't get paired
                    detected[i]=true;
                    detected[j]=true;

                    //this is collection of the final result
                    int c=dipoles[k][0].count[k]++; //dont get
                        confused, count is static, so even
                        dipoles[0][0] would've worked, ro for
                        that matter, any valid index
                    //Note the ++ is after because the count is
                        always one greater than the index of the
                        last element!


                    // dipoles[k][c].angle=(minEllipse[i].angle +
                         minEllipse[j].angle)/2.0;
                    // dipoles[k][c].angle=(minEllipse[i].angle);

                    // We're using two shapes, one ellipse and
                        one circle.
                    RotatedRect largerEllipse =  ( MAX(minEllipse
                        [i].size.width, minEllipse[i].size.height
                        ) > MAX(minEllipse[j].size.width,
                        minEllipse[j].size.height)  )?minEllipse[
                        i]:minEllipse[j];
                    RotatedRect smallerEllipse =  ( MAX(
                        minEllipse[i].size.width, minEllipse[i].
                        size.height) <= MAX(minEllipse[j].size.
                        width, minEllipse[j].size.height)  )?
                        minEllipse[i]:minEllipse[j];
                    dipoles[k][c].angle=(largerEllipse.angle);

                    dipoles[k][c].order=MAX(largerEllipse.size.
                        height, largerEllipse.size.width);

                    dipoles[k][c].x=largerEllipse.center.x; //(
                        minEllipse[i].center.x + minEllipse[j].
                        center.x)/2.0;
                    dipoles[k][c].y=largerEllipse.center.y; //(
                        minEllipse[i].center.y + minEllipse[j].
                        center.y)/2.0;
```

```
//Now we use the circle to remove the mod 180
     problem and get the complete 360 degree
    position
if((smallerEllipse.center.y -largerEllipse.
    center.y) < 0)
  dipoles[k][c].angle+=180;

dipoles[k][c].e1=i; //don't know why this is
    required
dipoles[k][c].e2=j;




//////////////THIS IS FOR RECORDING/SAVING
    THE DIPOLE MOVEMENT/////////////
if (dipoleRec==true)
{

  long cf=dipoleData.size()-1;  //last frame


  for(int q=0;q<seedDipole.data.size();q++)
  {
    //This is to test which dipole belongs
        where in accordance with the
        seedDipole frame
    // if(MAX(abs(seedDipole.data[q].x -
        dipoles[k][c].x), abs(seedDipole.data
        [q].y - dipoles[k][c].y)) < (
        seedDipole.order/2.0) )
    //Or you could use the last fraame for
        this
    if(
      (MAX(abs(dipoleData[cf-1].data[q].x -
          dipoles[k][c].x), abs(dipoleData[cf
          -1].data[q].y - dipoles[k][c].y)) <
           (dipoleData[cf-1].order/2.0) )
      &&
      (dipoleData[cf].data[q].detected==false
          )
      )
    {
      dipoles[k][c].id=q;
      // dipoleData.data[q] = dipoles[k][c]
      //TODO: Make a function for converting
      dipoleData[cf].data[q].x=dipoles[k][c].
          x; //Copy the relavent data from
          the dipole data collected into the
          temp dipole
      dipoleData[cf].data[q].y=dipoles[k][c].
          y;
```

```
                        dipoleData[cf].data[q].angle=dipoles[k
                            ][c].angle;
                        dipoleData[cf].data[q].
                            instAngularVelocity=0;
                        dipoleData[cf].data[q].detected=true;
                              //This is true only when the
                            dipole's

                        dipoleData[cf].order=dipoles[k][c].
                            order; //This is bad programming..i
                             should average, but doens't matter
                        //Now that it has matched, terminate
                            the loop
                        q=seedDipole.data.size();
                      }
                    }


                  }









              }
              // magnitude(differenceVector.x,differenceVector.
                  y,distance);

              // point positionVector ((minEllipse[i].x +
                  minEllipse[j].x)/2.0,(minEllipse[i].y +
                  minEllipse[j].y)/2.0);

            }
          }
        }
      }
    }

    //////////////DRAWING THE CONTOUR AND DIPOLE
    /// Draw contours + rotated rects + ellipses
    Mat drawing = Mat::zeros( threshold_output.size(), CV_8UC3 );
    for( size_t i = 0; i< contours.size(); i++ )
       {
         // Scalar color = Scalar( rng.uniform(0, 255), rng.
             uniform(0,255), rng.uniform(0,255) );
        Scalar color = Scalar(0,0,255 );
         // contour
         drawContours( drawing, contours, (int)i, color, 1, 8,
             vector<Vec4i>(), 0, Point() );
```

```
        // ellipse

        ellipse( drawing, minEllipse[i], color, 2, 8 );

        // rotated rectangle
        // Point2f rect_points[4]; minRect[i].points(
            rect_points );
        // for( int j = 0; j < 4; j++ )
        //    line( drawing, rect_points[j], rect_points[(j+1)
            %4], color, 1, 8 );
       // }


       // int xx=dipoles[k][i].x;
       // int yy=dipoles[k][i].y;
       // int theta=dipoles[k][i].angle;

       // line(drawing, Point2f(xx,yy),Point2f(xx + 5*cos(theta)
           , yy + 5*sin(theta)), Scalar(0,0,255),1,8);









     }

  for( int i=0;i<dipoles[0][0].count[k];i++)
  {

    int xx=dipoles[k][i].x;
    int yy=dipoles[k][i].y;
    float theta = (3.1415926535/180) * dipoles[k][i].angle;

    line(drawing, Point2f(xx - 5*cos(theta), yy - 5*sin(theta))
        ,Point2f(xx + 5*cos(theta), yy + 5*sin(theta)), Scalar
        (0,255,255),5,8);



    // Use "y" to show that the baseLine is about
    char text[30];
    // dipoles[0][0].count[0]=1;
    // sprintf(text,"%f",dipoles[0][dipoles[0][0].count[k]-1].
        angle);

    int fontFace = FONT_HERSHEY_SCRIPT_SIMPLEX;
    double fontScale = 0.5;
    int thickness = 1;

    int baseline=0;
```

```
    Size textSize = getTextSize(text, fontFace,
                                fontScale, thickness, &baseline
                                    );
    baseline += thickness;

    // center the text
    Point textOrg((drawing.cols - textSize.width)/2,
                  (drawing.rows + textSize.height)/2);
      // // draw the box
      // rectangle(drawing, textOrg + Point(0, baseline),
      //           textOrg + Point(textSize.width, -textSize.
          height),
      //           Scalar(0,0,255));
      // // ... and the baseline first
      // line(drawing, textOrg + Point(0, thickness),
      //      textOrg + Point(textSize.width, thickness),
      //      Scalar(0, 0, 255));

      // then put the text itself
      // putText(drawing, text, textOrg, fontFace, fontScale,
          Scalar::all(255), thickness, 8);
    sprintf(text,"%1.1f",dipoles[k][i].angle);
    putText(drawing, text, Point(dipoles[k][i].x,dipoles[k][i].
        y), fontFace, fontScale, Scalar::all(0), thickness*3,
        8);
    putText(drawing, text, Point(dipoles[k][i].x,dipoles[k][i].
        y), fontFace, fontScale, Scalar::all(255), thickness,
        8);

    sprintf(text,"%d,%d",dipoles[k][i].id,i);
    putText(drawing, text, Point(dipoles[k][i].x,dipoles[k][i].
        y-10), fontFace, fontScale, Scalar::all(0), thickness
        *3, 8);
    putText(drawing, text, Point(dipoles[k][i].x,dipoles[k][i].
        y-10), fontFace, fontScale, Scalar(255,255,0),
        thickness, 8);

  }
  imshow( "Contours", drawing );



  ////////////////////////////
  //  THIS IS HOUGH
  ////////////////////////////
  // // cvtColor(img, cimg, CV_GRAY2BGR);
  // // cimg=src_gray;
  // // Mat cimg();
  // Mat cimg(src.rows,src.cols, CV_8UC3, Scalar(255,255,255));

  // vector<Vec3f> circles;
  // HoughCircles(src_gray, circles, CV_HOUGH_GRADIENT, 1, 10,
```

```
//              canny, centre, minMinorAxis, maxMajorAxis //
    change the last two parameters
//                              // (min_radius & max_radius)
    to detect larger circles
//              );

// // src_gray:s Input image (grayscale)
// // circles: A vector that stores sets of 3 values: x_{c},
    y_{c}, r for each detected circle.
// // CV_HOUGH_GRADIENT: Define the detection method.
    Currently this is the only one available in OpenCV
// // dp = 1: The inverse ratio of resolution
// // min_dist = src_gray.rows/8: Minimum distance between
    detected centers
// // param_1 = 200: Upper threshold for the internal Canny
    edge detector
// // param_2 = 100*: Threshold for center detection.
// // min_radius = 0: Minimum radio to be detected. If
    unknown, put zero as default.
// // max_radius = 0: Maximum radius to be detected. If
    unknown, put zero as default

// for( size_t i = 0; i < circles.size(); i++ )
// {
//     Vec3i c = circles[i];
//     // Scalar color = Scalar( rng.uniform(0, 255), rng.
    uniform(0,255), rng.uniform(0,255) );
//     Scalar color = Scalar( 255,255,0 );
//     circle( cimg, Point(c[0], c[1]), c[2], color, 3, CV_AA
    );
//     circle( cimg, Point(c[0], c[1]), 2, color, 3, CV_AA);
// }

// imshow("Hough", cimg);


//////////////////////
// CLI
//////////////////////
char key = (char) waitKey(5); //delay N millis, usually long
    enough to display and capture input
int kMax; //sorry, bad programming, but relatively desparate
    for results..
switch (key)
{

    case 'c':
      mode=1;
      cout<<"Mouse will capture color now. Right click for
          one, left for the other";
      break;
    case 's':
```

```
        mode=0;
        cout<<"Screen crop mode selected. Mouse will capture
            start point at left click and the other point at
            right click";
        break;
      case 'p':
        cout<<"Frame will be used as a seed";
        dipoleRec=true; //Enable dipole recording
        seedDipole.data.clear();  //clear the data
        dipoleSkel tempDipole;  //create a temporary dipole
            skeleton
        k=dipoles[0][0].current;  //find the current buffer of
            dipoles detected (double buffered for possible
            multithreading)
        kMax=dipoles[0][0].count[k]; //find the number of
            dipoles detected in the last scan

        for(int c=0;c<kMax;c++)
        {
          tempDipole.x=dipoles[k][c].x; //Copy the relavent
              data from the dipole data collected into the temp
               dipole
          tempDipole.y=dipoles[k][c].y;
          tempDipole.angle=dipoles[k][c].angle;
          tempDipole.instAngularVelocity=0;
          tempDipole.detected=false;   //This is to ensure the
              dipole was detected, but for the seed frame, it
              is left false.
          seedDipole.data.push_back(tempDipole);  //Add the
              data in the seedframe's data stream

          seedDipole.order+=dipoles[k][c].order;  //to get teh
              average order
          if(c>0)
          {
            seedDipole.order/=2.0;
          }
        }
        seedDipole.time=0; //Initial time is to be stored as
            zero
        dipoleData.push_back(seedDipole);

        break;
      case 'w':
        cout<<"Writing angle vs time for the first dipole to
            file";
        if(dipoleRec==true)
        {
          sprintf(fileName,"latticeAnalyser_%d",getTickCount())
              ;
          pFile = fopen (fileName,"w");
```

```
            //Loop through all the frames
            for (vector<dipoleFrame>::iterator dD = dipoleData.
                begin() ; dD != dipoleData.end(); ++dD)
            {
              //Within each frame, loop through all dipoles?
              // for(vector<dipoleSkel>::iterator dS = dD.data.
                  begin() ; dS!=dD.data.end() ; ++dS)
              // {

              // }
              //or just print the first dipole
              if(dD->data[0].detected)
                fprintf (pFile, "%f,%f\n",dD->data[0].angle,dD->
                    time);
              // fprintf (pFile, "%d,%d\n",dD->data[0].angle,dD->
                  time);
            }


            // for (int p=0;p<dipoleData.size();p++)
            // {
            //   fprintf(pFile,"%d,%d\n",dipoleData[p].data.size
                ),dipoleData[p].time);
            // }
            fclose (pFile);
            // fprintf (pFile, "Name %d [%-10.10s]\n",n,name);

          }
          break;
        case 'q':
        case 'Q':
        case 27: //escape key
            return 0;
        // case ' ': //Save an image
        //     sprintf(filename, "filename%.3d.jpg", n++);
        //     imwrite(filename, frame);
        //     cout << "Saved " << filename << endl;
        //     break;
        default:
            break;
    }
  }
  return 0;


}

/**
 * @function main
 */
int main( int ac, char** argv )
{
```

```
////Voodoo intializations
// dipoles[0][0].current=0;
// dipoles[0][0].count[0]=0;
// dipoles[0][0].count[1]=0;


/// Create Window

namedWindow( source_window, WINDOW_AUTOSIZE );
setMouseCallback( "Source", onMouse, 0 );
// createTrackbar( " Threshold:", "Source", &thresh, max_thresh
    , thresh_callback);
//CAN BE ENABLED, but causes problems, the following lines, to
    the color detection
// createTrackbar( " Threshold:", "Source", &thresh, max_thresh
    , 0);


//Show the filtered image too

namedWindow( filter_window, WINDOW_AUTOSIZE );

//Show the settings window

namedWindow(settings_window,WINDOW_AUTOSIZE  | CV_GUI_NORMAL);
createTrackbar( "ColorA Tolerance", settings_window, &colorATol
    , 256, 0 );
createTrackbar( "ColorB Tolerance", settings_window, &colorBTol
    , 256, 0 );
createTrackbar( "Min Radius (Hough)", settings_window, &
    minMinorAxis, 100, 0 );
createTrackbar( "Max Radius (Hough)", settings_window, &
    maxMajorAxis, 200, 0 );
createTrackbar( "Canny (Hough)", settings_window, &canny, 200,
    0 );
createTrackbar( "Centre (Hough)", settings_window, &centre,
    200, 0 );
// createTrackbar( "Theta", settings_window, &thetaD, 3.141591,
     0 );

/// Show in a window
namedWindow( "Contours", WINDOW_AUTOSIZE );
namedWindow( "Hough", WINDOW_AUTOSIZE );


/// Load source image
// src = imread( argv[1], 1 );
std::string arg = argv[1];
VideoCapture capture(arg); //try to open string, this will
    attempt to open it as a video file
```

```
  if (!capture.isOpened()) //if this fails, try to open as a
      video camera, through the use of an integer param
      capture.open(atoi(arg.c_str()));
  if (!capture.isOpened())
  {
      cerr << "Failed to open a video device or video file!\n" <<
           endl;
      return 1;
  }

  process(capture);

  return 0;
}
```

2.2.3 *Construction of the Dipole*

COLOPHON

This document was typeset using the typographical look-and-feel `classicthesis` developed by André Miede, for LaTeX.
The style was inspired by Robert Bringhurst's seminal book on typography "*The Elements of Typographic Style*".

The latest version of this document is available online at:

https://github.com/toAtulArora/IISER_repo