

DIPOLE LATTICE

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Upscaling a nano-structure

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*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)

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

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

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ACRONYMS

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 with a glass slide at the bottom. This 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).

WATCH IT GROW

2.1 SENTIMENTAL INTRODUCTION¹

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.

2.2 THE JOURNEY

2.2.1 *Look it has begun*

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 significantly simplified by the prior work.

1. The Dipole

This had one apparent problem; the dipoles had to be made virtually frictionless (which is not to say they had excessive friction, infact they would oscillate atleast about 8 times before stopping aligned with earth's magnetic field)

2. The Image Analysis

This part I had to start from the beginning with two basic objectives, as stated earlier; measuring the angle of the dipoles and evaluating the current to be pumped based on the temperature selected.

What was known soon, was that C++ will be used for programming and linux would be the operating system, to facilitate USB interface with the AVR (next step)

3. The Current Control Hardware

This is simply for providing a current pulse proportional to the intensity calculated by the lattice analyser. Some schematics for this were available, but were found to be inaccurate and incomplete.

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

2.2.2 Time Line

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

Time Line

- ** May 18 and 19, Saturday and Sunday: Completing the documentation for the same. Thought of a way of testing the time lag.
- * 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 analyser 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 seemed to be perfect.
- * 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 latticeAnalyser. 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

2.2.3 Construction of the Dipole

To remove the friction, there were various ideas, including use of a super conductor. However, eventually three methods were considered and experimentally tested.

1. Ferro-Fluid:

As it turns out, there are substances that have a ferro magnetic properties but in the liquid form. Consequently, a strong enough magnet would glide if coated with this substance.

Experimentally, it was found that the friction was higher than the 'needle on glass' setup.

2. Magnetic Levitation:

A magnet can easily suspend another magnet, granted it doesn't flip. This idea was used and a magnetic cylinder was placed co-axial to the needle, using a cylindrical eraser and glue. Beneath the glass slide, an identical magnet was placed with the face that repels upwards.

Experimentally, again it was found that the motion was more damped than the 'needle on glass' setup. The reason for this case was obvious after a little analysis and closer observation. The dipole would align to the field of the magnet, viz. the magnetic field was interfering with the dipole.

3. Air Levitation: This hasn't been tested yet, but the idea is to put a disc at the bottom of the needle, and pass air through it to keep it suspended.

2.2.4 Construction of the Lattice Analyser

The lattice analyser has come a long way. Image detection trials were initiated with [Figure 1](#).

The idea was that once the ellipses have been detected, and they are different in colour, one can evaluate from their centroids, the position and the angle of the dipole. It must be stated that earlier it was attempted to use the greyscale image as was provided. However soon the shadow interference led to using coloured patterns instead. These patterns were not printed but displayed on a screen and the camera aimed appropriately.

So first, the algorithm for detection of relevant part of the image had to be frozen. There were two candidates for this



Figure 1: Sample Image

1. Hough Transform Method

Either one could use the already available in OpenCV, line detection or circle detection, both would've required changing the pattern on the dipole

Or one could use an ellipse modification for the same, which would require programming the algorithm.

2. Contour Detection and Ellipse Fitting

This method detects contours in a given image, and the OpenCV example also shows ellipse fitting for the same. This seemed promising too, but it seemed more expensive (computationally) than looking for predetermined shapes.

This work had been done within the first few days.

Next, a colour filter was to setup to improve the accuracy. When the algorithms were implemented, it was found that the Hough Transform method often misses detection of circles, refer to [Figure 2](#) (this is ofcourse after attaching a video stream instead of images to the code) as compared to contour detection [Figure 3](#).

After the detection, according the plan, two colours were to be used for the ellipses. However, running the hough transform twice would've dropped the detection speed to half, which wasn't worth it. It was then decided that the shapes should be made different instead of relying on two colours for the same information. After looking at various combinations, [Figure 4](#) was finalized, with an ellipse at the centre, and a circle along the minor axis for breaking the symmetry. This method did infact work as shown in [Figure 5](#).

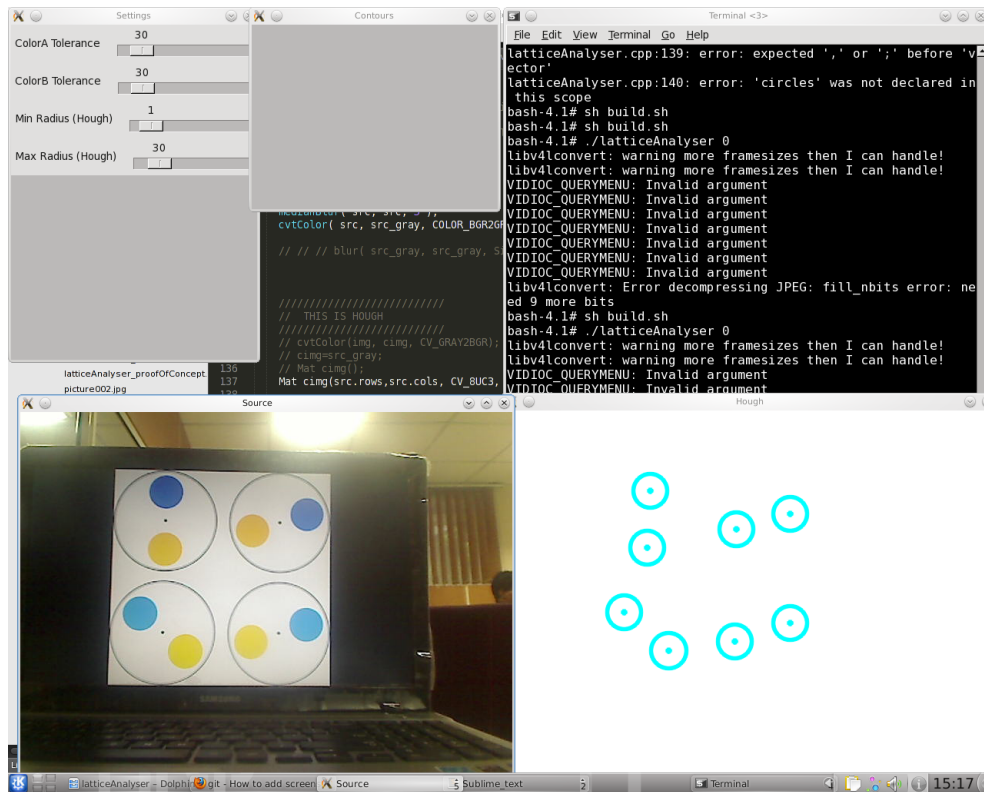


Figure 2: Hough Transform

The next challenge was to realize that a dipole detection can be missed and therefore mess up the counting, if that is the only way of uniquely identifying them. Unique identification is obviously required, as the external hardware must fire the coils of the right dipole. Thus a reference frame was used to uniquely identify the dipoles initially. This is expected to happen when they are stationary to get a good reading. In each frame, whenever a dipole is detected, it is associated with the dipole in the reference frame, by matching its location. If a dipole is not detected in a given frame, the software knows it was unable to record it and doesn't mess up neither the numbering nor the observations.

After implementation of the last part, an animation sequence was created in Power Point, with the dipoles rotating with a constant speed and the camera was aimed at the screen. A still from the same is given in Figure 7. Figure 6, shows the angular position versus time plot, for the first dipole and yes, it is linear, just as expected. Standard deviation tests are still to be done.

Following is the source code of the same, which has been made available online.

latticeAnalyser.cpp

```
/*
```

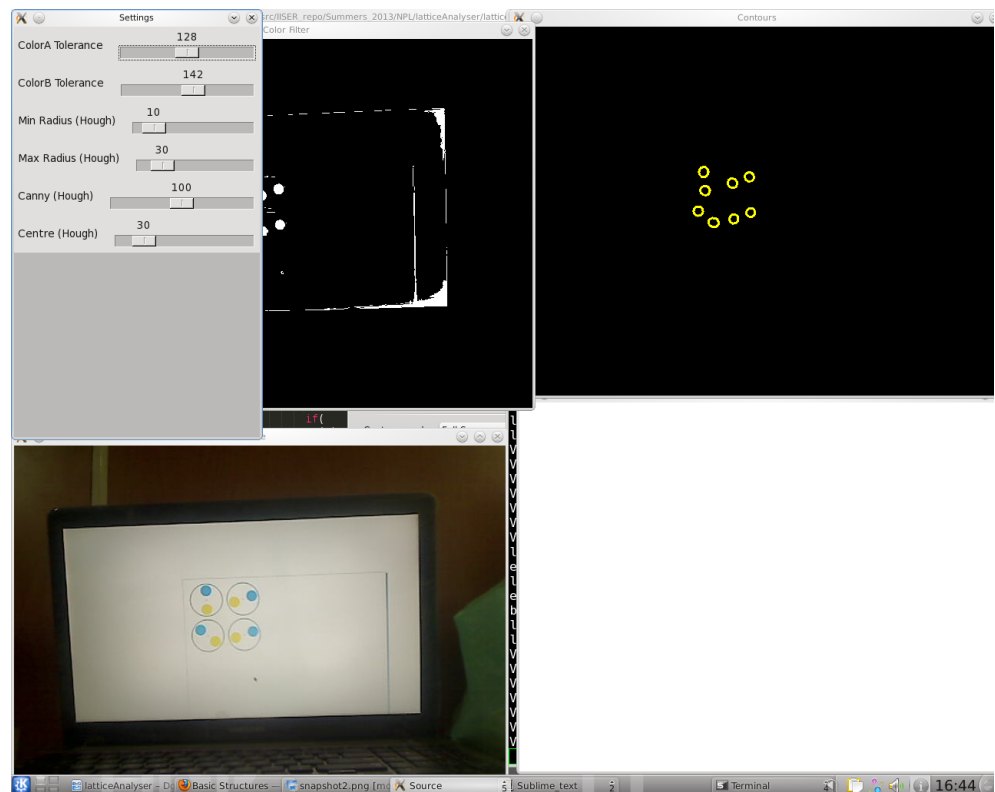


Figure 3: Contour Detection

```

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]

```

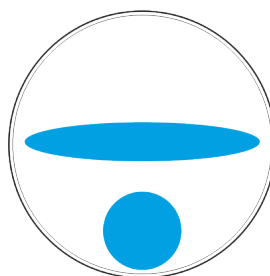


Figure 4: Final Pattern

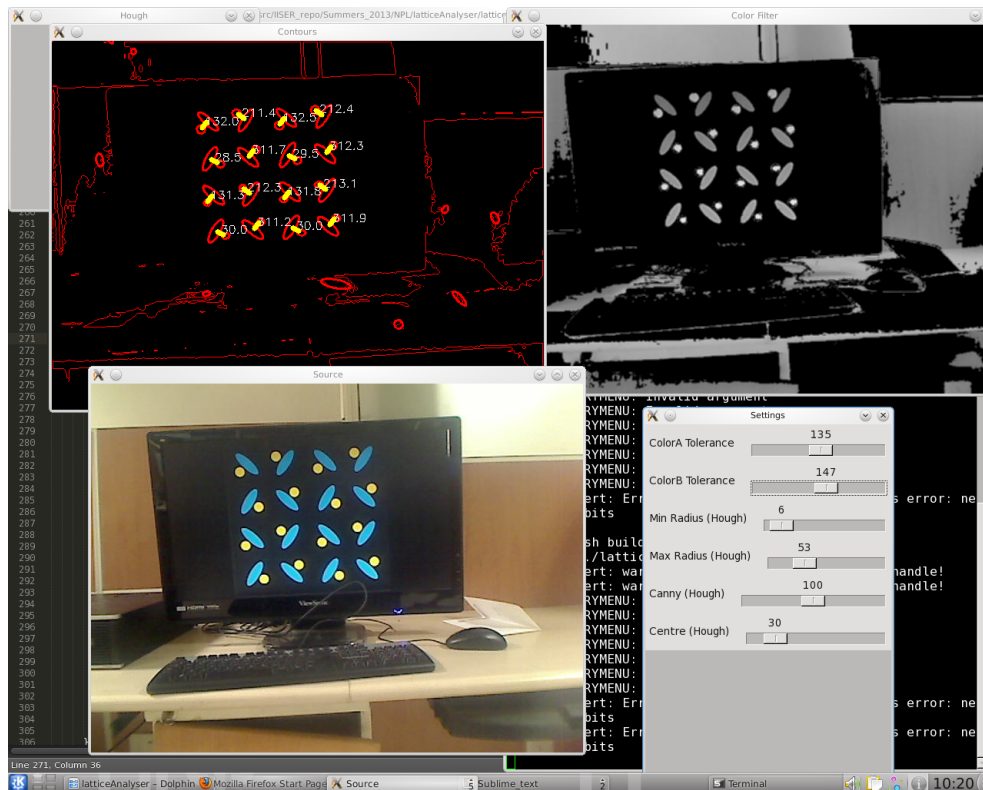


Figure 5: Multi Shape, Single Colour

```

    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]
3. Testing
    a. Test OpenCV's computation time
*/

#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;

```

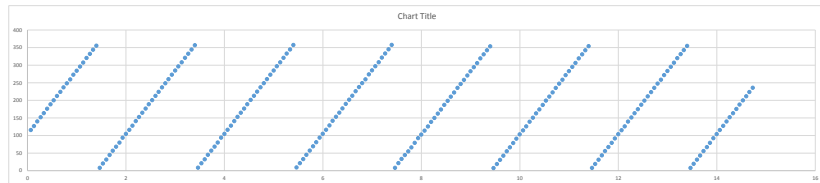


Figure 6: First Observation

```
using namespace std;

//For computation time
double tCstart,tCdelta,tCend; //time for computation
vector <double> computationTime;

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
```

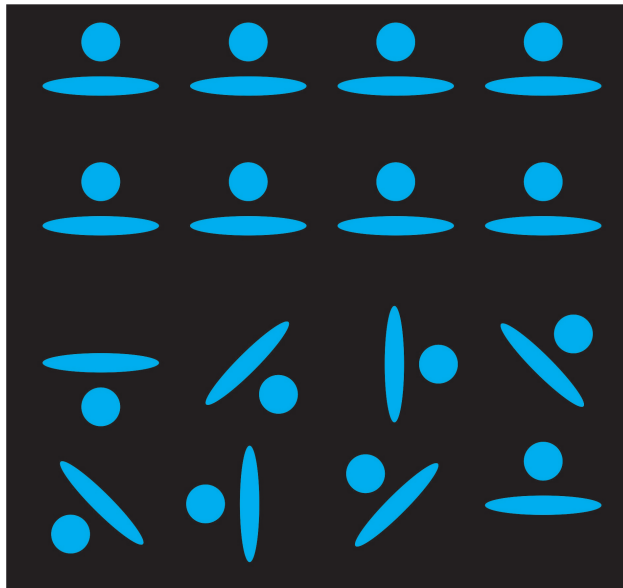



Figure 7: Final Test Pattern

```

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 array
// 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;
            ////////////////COMPUTATION TIME CALCULATION
            tCstart=getTickCount();
            ////////////////
            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 additional 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] 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 doesn'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);

//DEBUG ONLY
if(i==0)
{
    Mat cimg(src.rows, src.cols+500, CV_8UC3, Scalar(0,0,0));
    sprintf(text, "%1.1f", dipoles[k][i].angle);
    putText(cimg, text, Point(dipoles[k][i].x-50, dipoles[k][i].
        y), fontFace, fontScale*12, Scalar::all(255),
        thickness*4, 8);
    imshow("Hough", cimg);
}
}
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 relevant
    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 the
    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 'W':
    pFile=fopen("TestComputation","w");
    for(vector<double>::iterator d=computationTime.begin();
        d!=computationTime.end();++d)
    {
        fprintf(pFile,"%f\n",*d);
    }
    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;
}
tCend=getTickCount();
tCdelta=tCend-tCstart;
computationTime.push_back(tCdelta/getTickFrequency());
}
return 0;

}

/**

```

```

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

    ///Voodoo initializations
    // 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;
}
```


COLOPHON

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The latest version of this document is available online at:

https://github.com/toAtulArora/IISER_repo