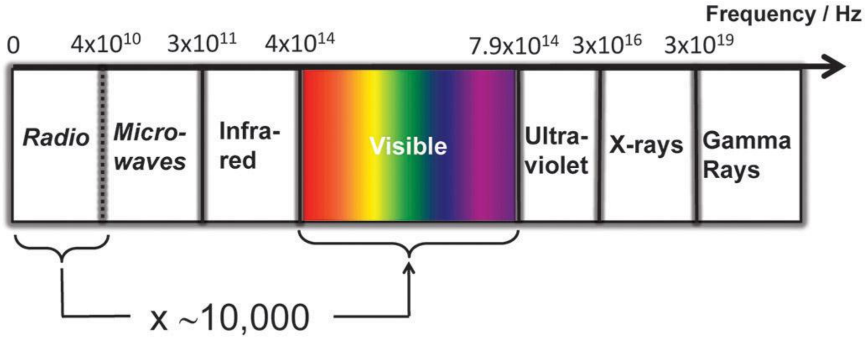
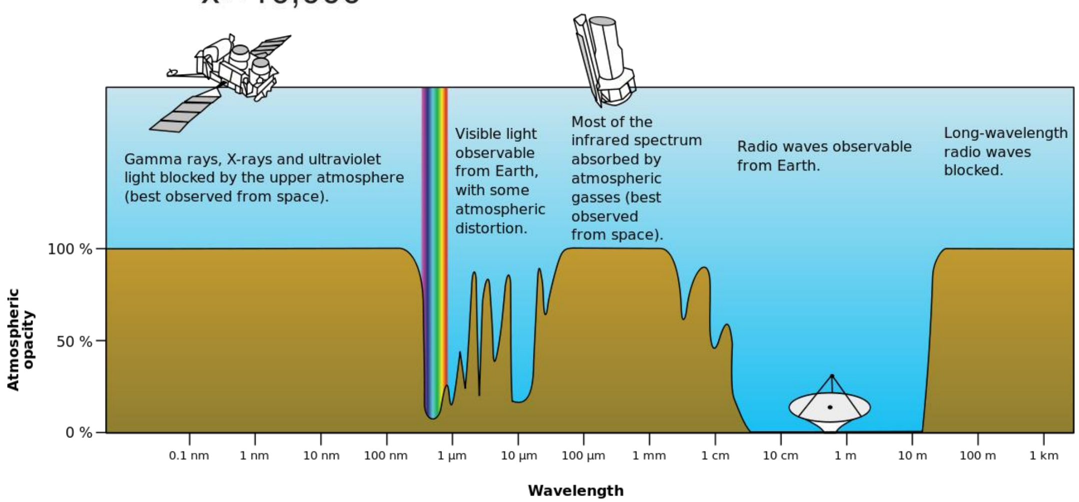
Swarm Robots In A Closed Loop Visual Odometry System By Using Li –Fi

Motivation for Li-Fi



- Too many RF devices
- Too much interference in RF spectrum
- Low bandwidth in Radio N/W
- Visible is 10,000 times of RF

(WDM it out for occupying entire spectrum)



Li-Fi was believed to be complex, so we wanted to give it a try at DIY level and explore the scope of Simple unidirectional VLC networks

Li-Fi goes everywhere

Hazardous environment
Communicating in areas where there is risk of explosions can be a problem (e.g. in mines, petro-chemical plants, oil rigs etc.) . VLC is inherently safe and provides both safe illumination and communications

Vehicle and Transportation
Many cars already LED lamps. Traffic signage, traffic lights, and street lamps are adopting the LED technology so there are massive applications opportunities here.

Defence and Security
The ability to send data quickly and in a secure way is the key to many applications. The fact that the visible light cannot be detected on the other side of a wall had great security advantages.VLC in Hospitals & Healthcare

Hospitals and Healthcare
There are advantages for using VLC in hospitals and in healthcare. Mobile phones and WiFi's are undesirable in certain parts of hospitals, especially around MRI scanners and in operating theatres.

WiFi Spectrum relief
WiFi's have got faster over but cannot keep up with demand for wireless data. VLC can provide data rates greatly in excess of current WiFi and this can be done at low cost since the RF components and antenna system have been eliminated.

Aviation
Radio is undesirable in passenger compartments of aircraft. LEDs are already used for illumination and can also be used instead of wires to provide media services to passengers. This reduces the aircraft construction costs and its weight.

Underwater Communications
RF does not work underwater but visible light can support

Motivation for Closed Loop Robots

- **Odometry** is the use of data from motion sensors to estimate change in position over time. Hence an important aspect in robotics.

- Needed closed loop, but traditionally,

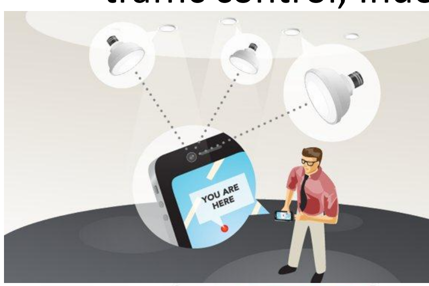
(i) it involves wheel encoders- not accurate
(ii) obstacle sensors – not enough
(iii) 2D laser scanners – too expensive

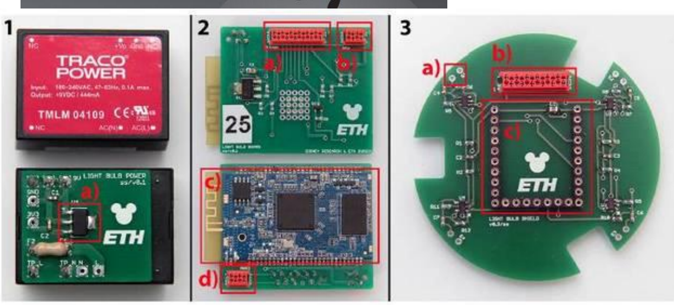
- Hence shifted to visual odometry- Efficient, cheap and requires one overhead camera and a PC
- The robots could be sent from A to B efficiently
- Robots could be assigned IDs and Pose estimation data could be directly acquired.

Concurrent Research in this domain

LiFi

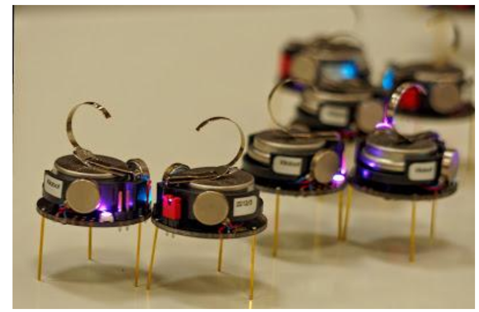
- Disney Research with ETH Zurich
  - Li-Fi OSI Model by Disney
  - Li-Fi Software for Sync
  - Bidirectional high rate LED communications
  - Feasibility for commercialization
- IEEE standards for Li-Fi are under process 802.15.7
- Commercialization and feasibility checks in various parts of the world – (Aeroplanes, traffic control, Indoor localizaton, etc)





Swarm robots and Odometry

- Robocup football robots
- Robocon Robots odometry
- SSL (Small sized league shared vision)

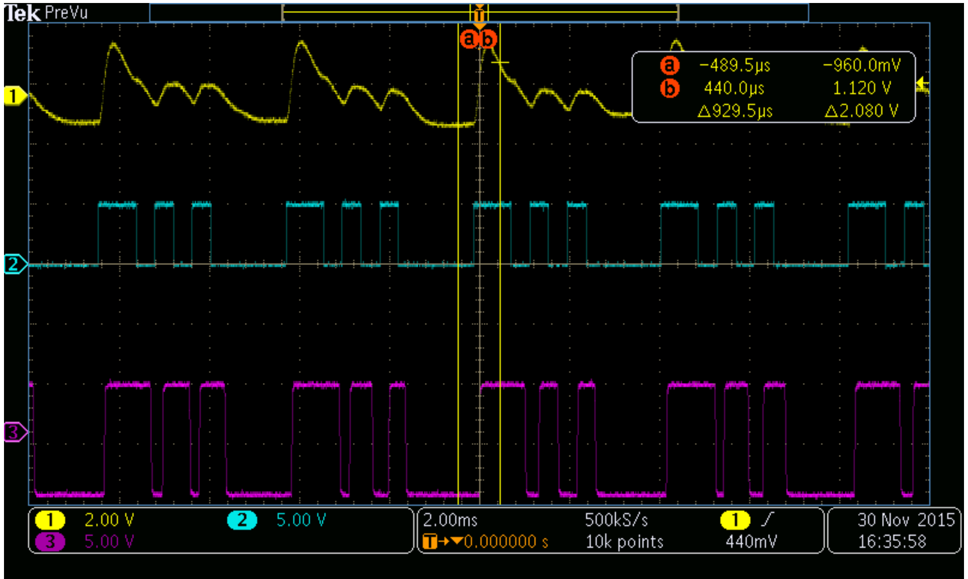


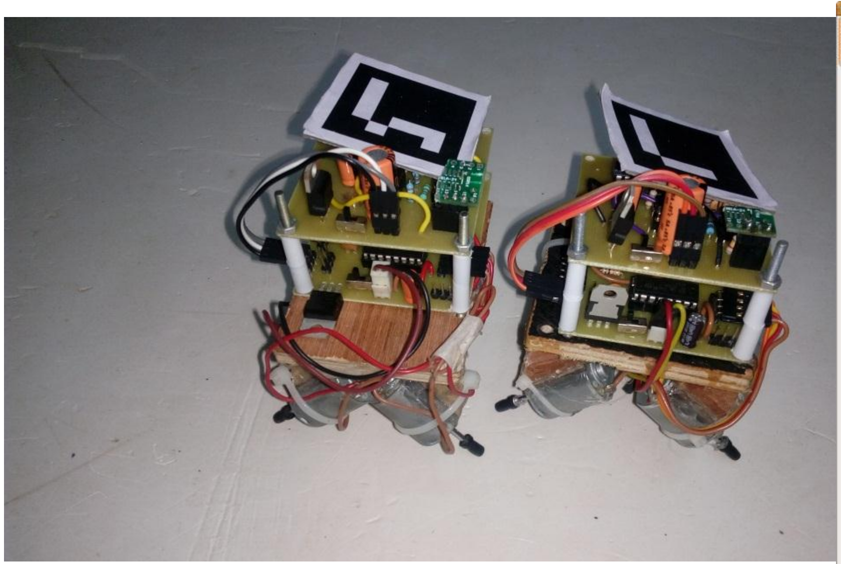
Differences from other Li-Fi and Swarm Environments

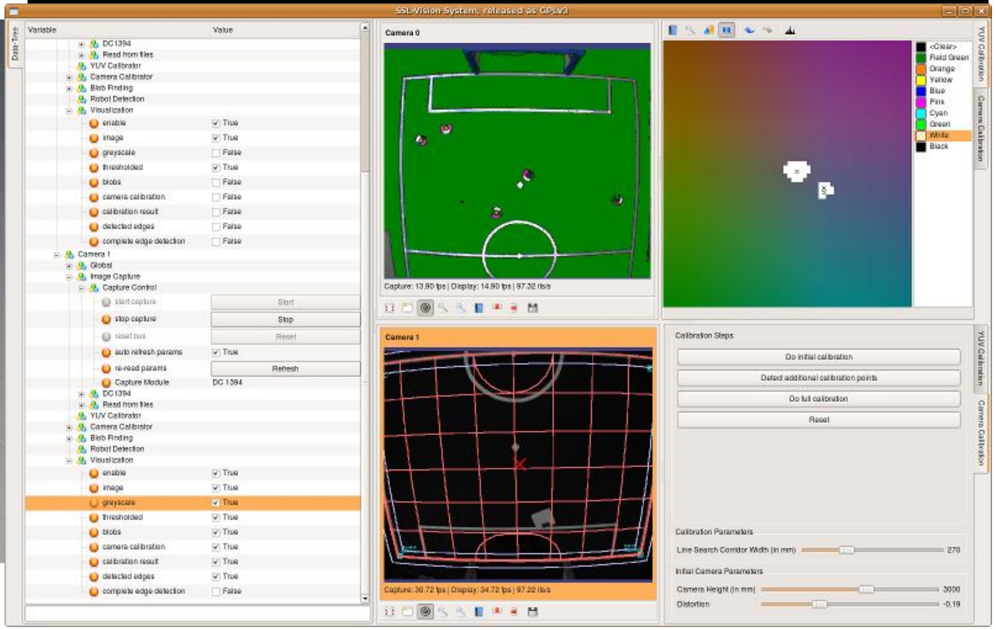
Them	**Us**
All the protocols devised by Disney Research are on straight line of sight setups kept 2 cms away from each other	We have a solid angle of sensitivity of 60° at a maximum of 3 meters
All the faster protocols implement complex OFDM and WDM techniques to multiplex data to increase baud rates	we implemented simple baseband modulation at unperceivable baud rates using off the shelf components and robots are pinged sequentially via TDMA
Swarm environments generally permit robots to communicate with each other and also have provisions for establishing closed loop by themselves	The protocols and environment we developed are also valid for dumb swarm robots (ones who do not have any provision for sensing or communicating)
Visual odometry is perfomed with SLAM (Simulataneous Localization and Mapping Techniques) by onboard cameras	We have a stationary overhead camera which acts as a mock GPS for all the robots. On calibration we can extract YPR+XYZ (orientation+location) data

Goal

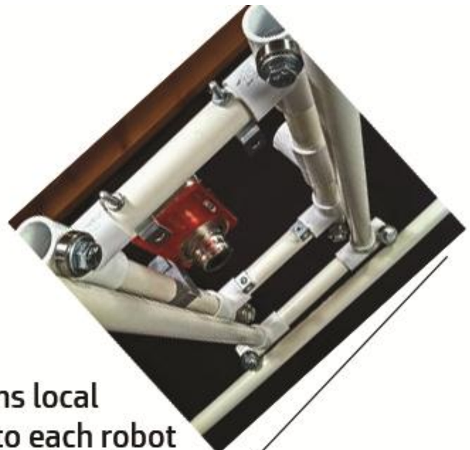
- To establish closed loop with visual odometry
- To create a flawless simplex Li-Fi system
- To perform swarming algorithms







Merged Li-Fi with Swarm to make closed loop swarm robots with Visual odometry

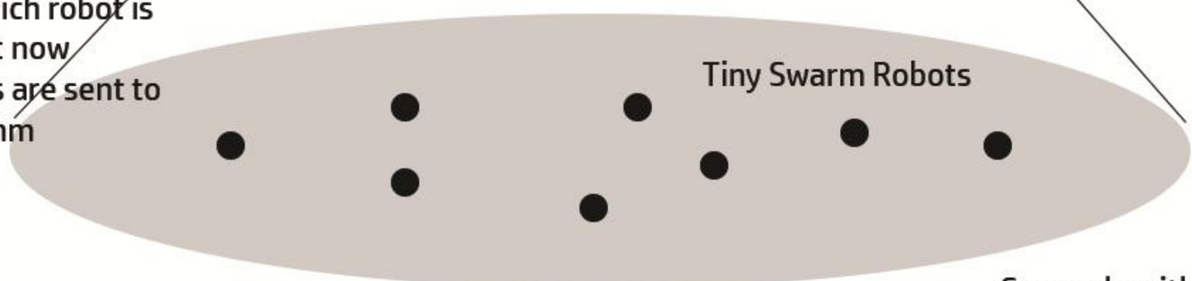


Visible light communication is
1) Assume you power a LED bulb
2) We switch that bulb on and off at very high speeds so it is imperceivable. This on and off has data modulated in it

10
0100
101101
10011010
0010110001

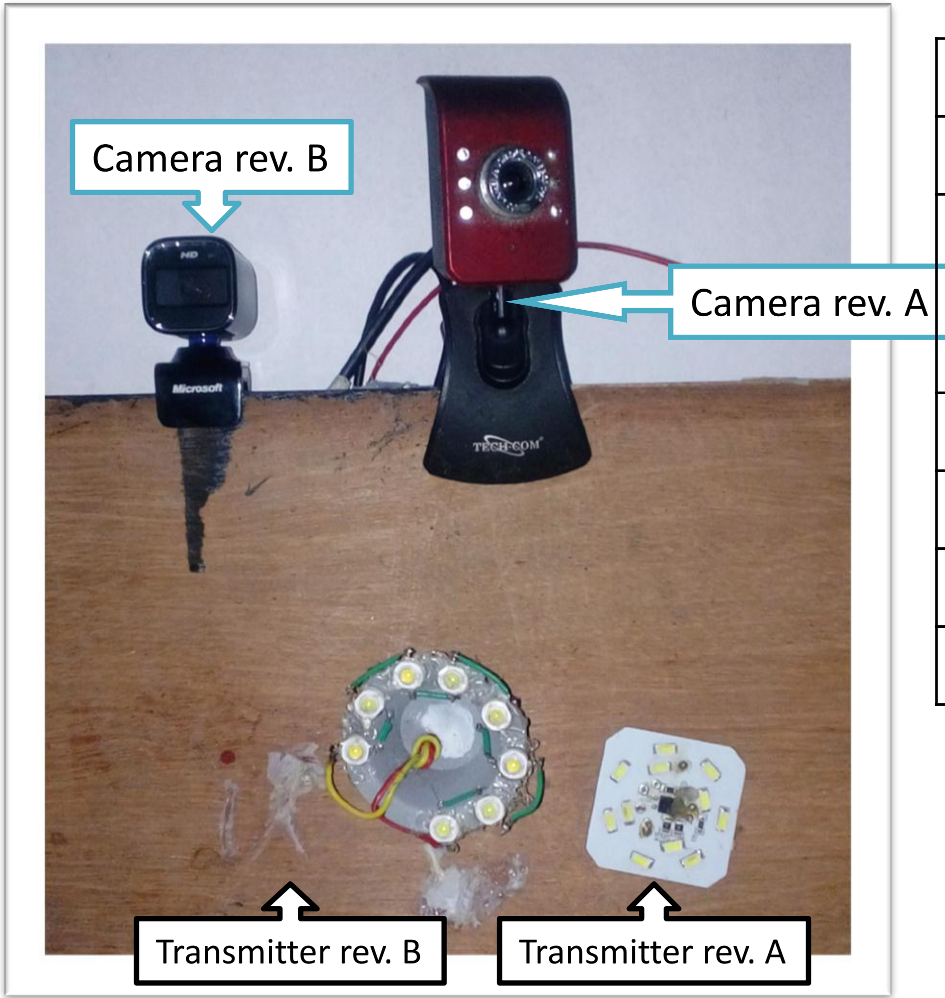
Commands Transmitted through Visible Light Communication

Camera assigns local co ordinates to each robot
This is done by taking the cameras feed in the laptop and finding out which robot is in which pixel right now
These co ordinates are sent to the swarm algorithm

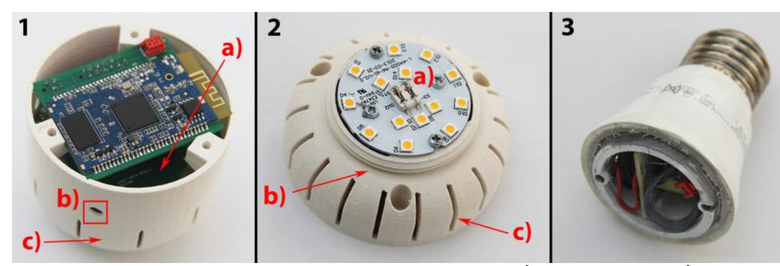


Some algorithms that would go in
1) Follow the leader robot
2) Minimize COM of the system
3) Minimum path from A to B without touching each other

LiFi Transmitter

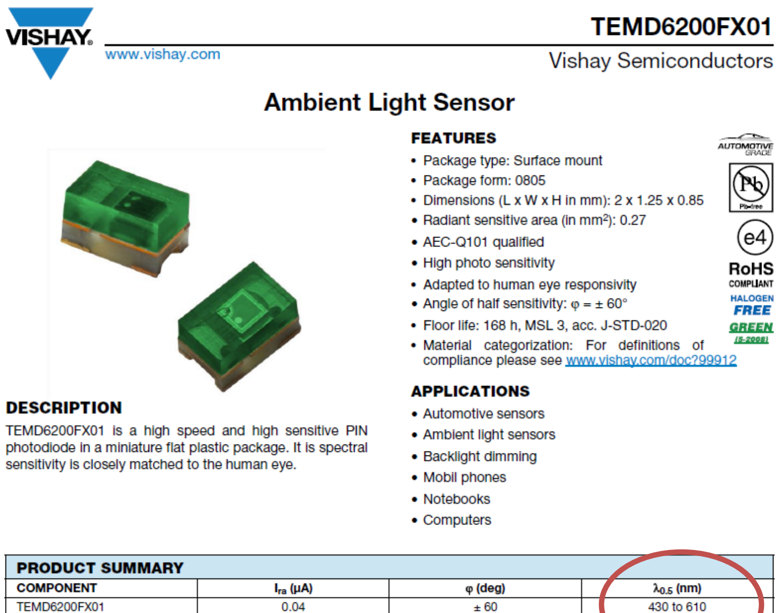


	Camera rev A	Camera rev B
Resolution	VGA: 480x480	HD : 1024x768
Features	Flash/no focus no IR filter (easy camshift and brightest point)	AutoFocus (easy marker detection) Algo2
	Tx LEDs rev A	**Tx LEDs rev B**
Power	36V 7W	27V 20W
Type	Phosphor	Phosphor
Features	W/O Heat SINK	With heat sink



LiFi transmitter by ETH Zurich

Choosing the LiFi Rx Tx



VISHAY.

www.vishay.com

TEMD6200FX01

Vishay Semiconductors

Ambient Light Sensor

FEATURES

- Package type: Surface mount
- Package form: 0805
- Dimensions (L x W x H in mm): 2 x 1.25 x 0.85
- Radiant sensitive area (in mm²): 0.27
- AEC-Q101 qualified
- High photo sensitivity
- Adapted to human eye responsivity
- Angle of half sensitivity: φ = ± 60°
- Floor life: 168 h, MSL 3, acc. J-STD-020
- Material categorization: For definitions of compliance please see www.vishay.com/doc?99912

AUTOMOTIVE GRADE

e4

RoHS COMPLIANT

HALOGEN FREE

GREEN (5-2008)

APPLICATIONS

- Automotive sensors
- Ambient light sensors
- Backlight dimming
- Mobil phones
- Notebooks
- Computers

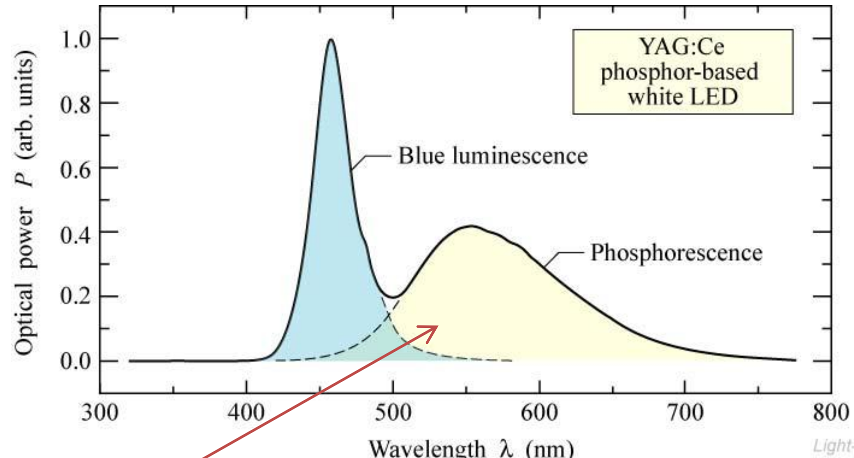
DESCRIPTION

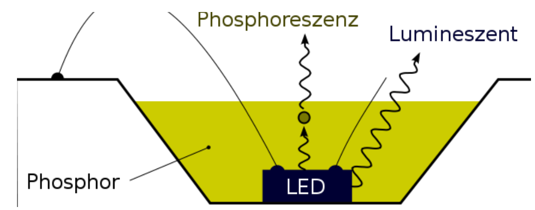
TEMD6200FX01 is a high speed and high sensitive PIN photodiode in a miniature flat plastic package. It is spectral sensitivity is closely matched to the human eye.

PRODUCT SUMMARY

COMPONENT	I_{ra} (µA)	φ (deg)	$\lambda_{0.5}$ (nm)
TEMD6200FX01	0.04	± 60	430 to 610

Rx

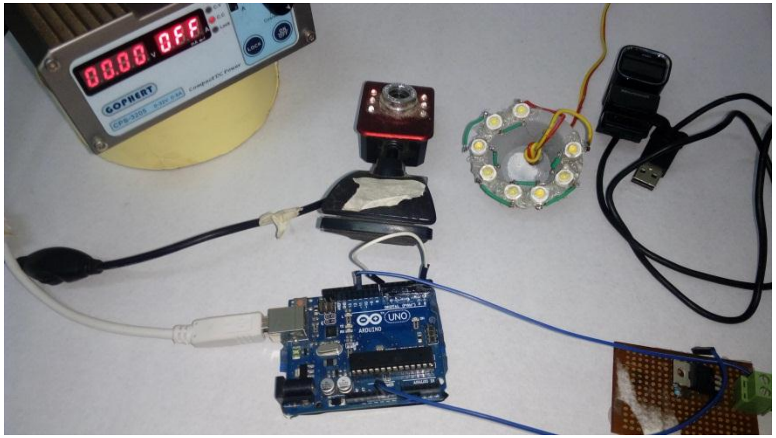




Tx

Setting up the Transmitter

- A COM port device to switch USB data to Serial UART data
- Echo-device to keep repeating last sent packet to keep the channel occupied always- or else external noise give garbage values @Rx end
- Arduino was chosen as the UART and repeater device and MOS IRF3710 was chosen as the switching device
- The receiver had a peak sensitivity around phosphor LED’s max power sub wavelength. Hence phosphor LED was chosen. The system was tested to work flawlessly at 3m even in the presence of external sunlight and other ambient lighting devices.
- The wattage was increased to increase the distance and parallel capacitor which prevented dimming was removed.
- Heat sinks were introduced to dissipate heat out of the LEDs to prevent burn-off

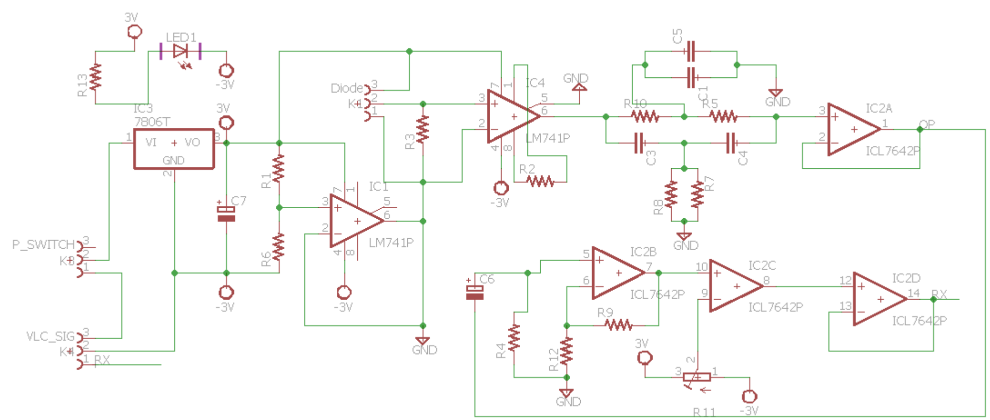


Setting up the Receiver

- had to deal with
  - -amplification
  - -noise
  - -filtering
  - -thresholding
  - -w/o loading effects on any end
  - -compatible with Arduino signal noise margin levels

Bottlenecks imposed due to	Slew Rates	Arduino processing power	Cost effectiveness	Inability to perform WDM and OFDM

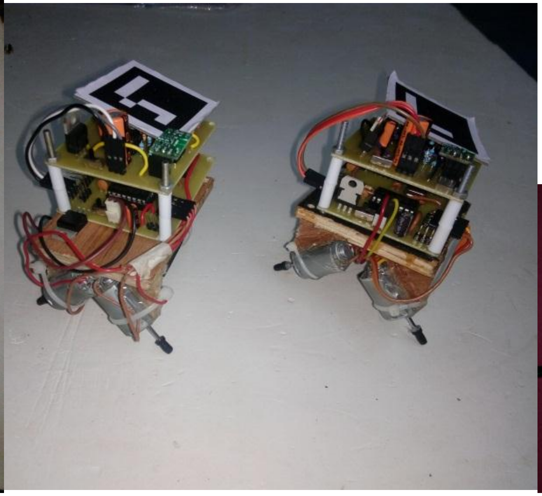
Rev A Temt6000- transistor		**Rev B Temd6200- diode**	
Advantage	Disadvantage	Advantage	Disadvantage
No trans-impedance reqd. to convert photocurrent to voltage	High junction capacitance, Slow discharge rates- slows baud	Low junction capacitance, Fast discharges, Faster baud	Trans-impedance stage reqd. to convert photocurrent to voltage



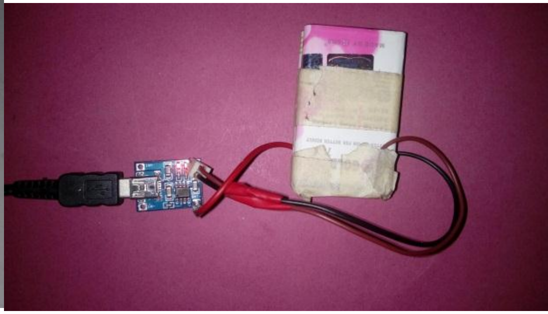
Setting up the bot

- The swarm bots had to be small in size
- Circuit CAD and Design CAD were fabricated
- Off board programming and charging
- Shifting boot-loaders to new AtMegas and interfacing motor drivers
- Motors were off the shelf 12v DC motors (mfg. by Mabuchi) without a gearbox since minimal torque could drag the robot. Wheel not coupled as it increased the radius and hence the torque reqd.
- Batteries were BL-5C Lithium Ions – standard 3.7V cellphone batteries. They were coupled in series to give out 7.4V at a capacity of 800mAh. Each robot can run for 2 hours on a single charge.

Programming the robot



Bots in action



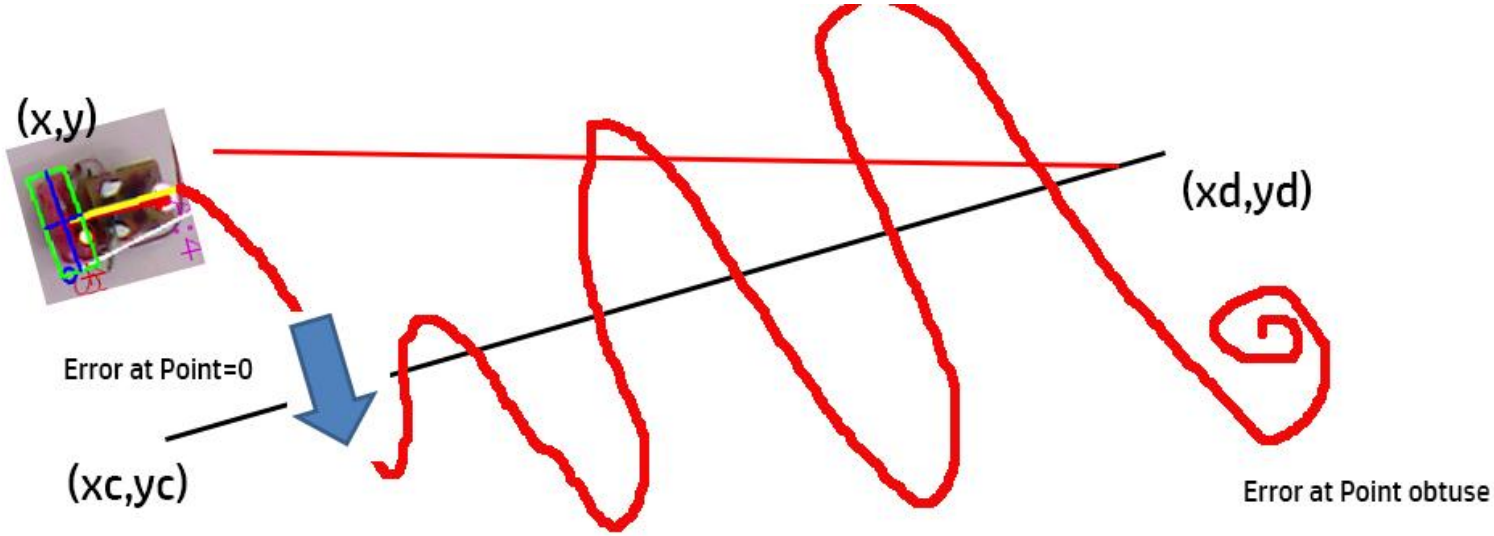
Charging the Li-Ion

Working on Image processing Algorithms

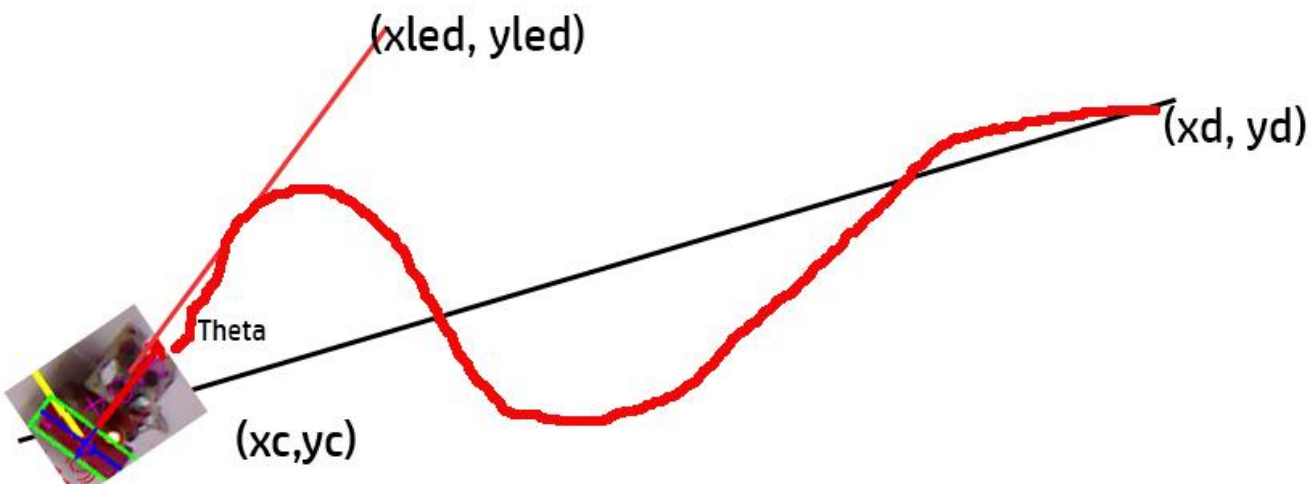
<u>Algorithms</u>	Rev A	Rev B	Rev C
Detection	HSV thresholding	Camshift	ARuco
Orientation info	NA	IR LED, Angle of CM and brightest point to give angle of robot	Pose estimation Edges of marker gives out angle of robot
Threading	CPU	Threaded to GPU	CPU
FPS	15	20	22
Error to destination	$Theta_{previouswithgoal}$ -$theta_{currentwithgoal}$	$Theta_{bot}$- $theta_{goal}$	$Theta_{bot}$- $theta_{goal}$
Efficiency	Least	Better	Best
Robot IDs	NA	IR LED of the destination robot is turned on	ARuco hamming codes
Multi-robot control	Not possible	Complex	Simple but requires Camera calib
Flowchart	1. Threshold via HSV 2. Convert to binary workspace 3. Erode & Dilate 4. cv::findContours 5. Moments[10] = centre of mass 6. Plot lines and select goal points	1. Backprojection with histogram normailization 2. meanShift to cluster contour 3. Track contour	1. Adaptive Thresholding 2. Findcontours 3. Polygonal approximation of 4 corners 4. Refine corners using subpixel interpolation 5. Frontal perspective of marker by homography 6. Otsu thresholding and hamming decode

Errors were sent in to GotoGoal **P controllers** which minimize the orientation error of each robot

Path trajectories before arriving to arUco



Method 1 : Issues due to single point constraints



Method 2 : Tracking using Brightest Point and

Includes and libraries used for final algorithm

```cpp
#include <opencv2/highgui.hpp>
#include <opencv2/aruco.hpp>
#include <opencv2/core/core.hpp>
#include "opencv2/calib3d/calib3d.hpp"

#include <opencv2/opencv.hpp>
#include <opencv2/imgproc/imgproc.hpp>
#include <opencv2/core/utility.hpp>
#include "opencv2/video/tracking.hpp"

#include <SerialStream.h>

#include <ctype.h>
#include <iomanip>
#include <sstream>
#include <string>
#include <iostream>
#include <vector>
#include <fstream>
#include <cstdlib>
#include <math.h>
#include <stdio.h>
#include <iomanip>
#include <unistd.h>

#define ABS(x) (((x)<0)?(0-(x)):(x))
#define SUB_X(x) (x - image.rows/2)
#define SUB_Y(x) (image.cols/2- x)

using namespace std;
using namespace cv;
using namespace LibSerial;

const char* const SERIAL_PORT_DEVICE = "/dev/ttyACM0";
```

OpenCV 2.4.9 Includes

Serial COM port includes for sending to repeater Arduino

String and character includes for packet compositions
Iomanip for constant packet lengths
And Math includes for angle and orientation calculations

Courtesy :
OpenCV organization for CV
'Aplicaciones de la Visión Artificial' from University of Cordoba for arUco

Path planning Algorithms

Path Planning Algo	Advantages	Disadvantages
A* algorithm	Heuristic analysis and solution	Works only on Static frame CPU Intensive
Diversion Node	No load on CPU Dynamic frame	Obstacle avoidance not guaranteed Not the shortest path to goal
Real time force field calculations	Shortest path to goal Not very CPU intensive Dynamic frame	Shortest path with obstacle avoidance

$$F = Q_r \left(C \frac{r_t}{||r_t||^2} + Q_r \sum_{i=1}^{K-1} \frac{r_i}{||r_i||^2} + \sum_{i=1}^{L} B_i \right)$$

Q_r is the robot potential, C is the target potential, r_t is a vector from the target to the robot, r_i is a vector from the moving robot to the i-th robot and B_i is the i-th barrier term. Each robot, barrier and target is assigned a constant potential, which corresponds to coefficients Q_r, B_r (which will be discussed soon) and C. Also, K is the number of robots on the testbed and L is the number of boundaries in the environment. The first two terms are simply a direct attraction or repulsion inversely proportional to distance. However, the boundary term is a bit different because we want the robot to go around the boundary instead of directly away from it. As shown in Figure 4.1, the robot feels a force perpendicular to the barrier instead of directly repulsing it. The robot only detects boundaries in the semicircle where the robot is facing, so this ensures the robot moves around the boundary.

$$B_i = B_r \left(\frac{r_B^{\perp}}{||r_B||^2} \right)$$

Serial Packets and Parsing

Type	Header	Instruction	Robot ID	Error	Trailer
Length	5 bytes	2 bytes	3 bytes	3 bytes	4 bytes
Description	"start" Start of frame	"30" : go "25" : stop	arUco robot ID	Heading error Offset by 180	"stop" End of frame
Example of typical frame	Start	30	768	200	stop

The frame composed : "start30768200stop"
Indicates
Robot no **768** should go in
Dynamic mode
With an error of **200**-180=20

Pwmright= fwd+20
Pwmleft=fwd-20
If fwd=80

Motorright will go forward with a speed of 100
MotorLeft will go forward with a speed of 60
And robot will differentially take a left.

The frame is broadcasted to all robots,
But the relevant ID robot picks up its error,
while other robots continue execution of
last error.

Error Refresh Rate per robot

- The error carried in the frame is 3/(5+2+3+3+4)th part of the frame.
- The baud rate currently is 19.2kbps
- The frames are sent out sequentially to N robots.
- Error refresh rate will hence be

$$\frac{(19200 \times 3)}{(N \times 17)}$$

Shifting to more ambitious steps

- Increasing the distance of communication and area of workspace
- Designing filters, diffusers and windows for transmitting and receiving LEDs
- Testing Swarm algorithms like Consensus, follow the leader and pattern formations
- Onboard programmers and charging on swarm bots

Inspiration	References-Swarm	References- LiFi
• Lifi-gets-ready-to-compete-with-wifi – IEEE spectrum article • 802.15.7 protocol article by IEEE on the infrastructure level implementation of LiFi • TED Talk by Harald Haas on Li-Fi on every bulb	• Michael Rubenstein on "Kilobot: A low cost scalable robot system for collective behaviors" at "Robotics and Automation (ICRA), 2012 IEEE International Conference" • Bin Feng, Yuan Gao on “Development of Strategy Software Algorithm Simulators for Multi-Agent System in Dynamic Environments Technology and Communication” -2013 from Vaasan Ammattikorkeakoulu VAMK, University of Applied Sciences • Paril Jain, “Odometry and motion planning for omni drive robots” Computational Intelligence on Power, Energy and Controls with their impact on Humanity (CIPECH), Nov 2014 • Datasheet, Atmel co-operation Atmega 328 datasheet for PWM and USART	• Harald Haas on "Principles of LED Light Communications Towards Networked Li-Fi" published with “Cambridge University Press” in 2015 being editor of IEEE Transactions on Communications and IEEE Journal of Lightwave Technologies • Stefan Mangold, “Linux Light Bulbs: Enabling Internet Protocol Connectivity for Light Bulb Networks” at “Workshop on Visible Light Communication Systems (VLCS)” on September 7, 2015 • Stefan Mangold, “Using Consumer LED Light Bulbs for Low-Cost Visible Light Communication Systems” at “Workshop on Visible Light Communication Systems (VLCS)” on September 7, 2014 • Stefan Mangold, “ LED-to-LED Visible Light Communication Networks” at “ACM International Symposium on Mobile Ad Hoc Networking and Computing (ACM MobiHoc)” on August 1, 2013 • Luis Orozco on “Optimizing Precision Photodiode Sensor Circuit Design” published in “Application notes of Analog Devices, Inc” for Transimpedance stage in Receivers • Bruce Carter on “Filter Design in Thirty Seconds” published in “High Performance Analog Texas Instruments” • Datasheet: TEMD6200FX01 by Vishay Semiconductors • Ambient Light Sensors - Circuit and Window Design Vishay – filtering amplifying and window size • http://www.lifi.eng.ed.ac.uk/li-fi-research-publications