Point-of-Care Medical Diagnostic Using Smart Phone

A cost effective and mobile platform to analyze blood samples.

Smartphone Microscopy
SMARTSCOPE

PIII Project Report

By,

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Guide

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Approval Sheet

Industrial Design Project III

Point-of-care medical diagnostic using smartphone.

by **Omkar R Jambovane**

M. Des. Industrial Design 2013-15

is approved as partial fulfilment of requirement of post-graduate degree in Industrial Design.

Internal examiner

Prof N.Sadhu
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External Examiner

Chairperson

Smartphone Microscopy
SMARTSCOPE

Declaration

I declare that this written submission represents my ideas in my own words and where others' ideas or words have been included, I have adequately cited and referenced the original sources. I also declare that I have adhered to all the principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/ data/ fact/source in my submission. I understand that any violation of the above will be cause for disciplinary action by the Institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

Signature:

Name: Omkar R Jambovane

Roll No.: 136130011

Date: 24/04/2014

With heavy heart, dedicated to my late father,
Ranappa Jambovane *(1943-2011)*
—an amazing soul, painter and sculptor—
who instilled in me the value of honesty,
pursuing higher education, and always aspiring for excellence.

Abstract

The remote health monitoring and disease detection in the Rural India are hampered by a lack of accurate, convenient and affordable diagnostic tests. As per my field study I observed that many of the basic tests administrated in well equipped clinical laboratories are inappropriate for the setting encountered at the point of care, where poor or even low-income patients may be best served. To address this problem, I have designed a smart scope which is useful for conducting rapid basic tests at the point of care by a single patient or a person who can conduct these tests door to door and carry the sample to the clinics in rural India. This project is a design of the initial implementation of diagnostics, with a smartphone application that supports health workers in rural India.

Acknowledgement

I cannot but acknowledge the unquantifiable help God gave me throughout this project work, always showing up whenever I got to the end of my line and felt like changing the project to a simpler one. Most remarkable was the breakthrough He gave me when I was stuck at point for a week!

I wish to express my deep gratitude towards Prof N. Sadhu Without whom none of this would have ben possible. Very soft spoken and always helpful, I learnt a lot from him.

Also, I must acknowledge my brother Sachin Jambovane for his love and support during entire project, Who encouraged me to work on this project. The acknowledgement, and consequently the report, would be incomplete without thanking all IDC staff.

I also express my thanks to my friends Naman, Tushar and Trivikram for their constant support and help.

- Omkar Ranappa Jambovane
136130011 | Sr PD

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Introduction

Medical devices intended for use in rural India have certain differences compared to those used almost everywhere else. In this project primary research work, focusing on the inherent problems in India (rural India, to be specific) and elucidate design constraints and approaches to develop better infrastructure in the way of medical devices leading to a better rural healthcare system. Over 70% of India's population lives in a rural setting. Hence, it goes without saying that providing adequate healthcare to this group is of paramount importance. In order for that, the ideal plan is to come up with a whole new healthcare delivery system.

Rural Health Issues

As mentioned before, rural India contains almost 70% of India's total population and more than half of it lives below the poverty line. They struggle for better and easier access to health care and services. The health issues faced by rural people are diverse and many; from severe malaria to diabetes, from an infected wound to cancer. Post-partum maternal morbidity is also one of the more serious(yet often neglected) problems in a resource-poor setting. Rural medical practitioners are highly sought after by people living in rural India as they more affordable and accessible than practitioners working in the formal public health care sector.

Image 1 : *The PHC in Hindalga village*

Primary Study

NATIONAL LEVEL Ministry of Health and Family Welfare	
STATE & UT's Department of Health Family Welfare	
Apex Hospitals	
DISTRICTS District Hospitals	
RURAL AREAS	**URBAN AREAS**
Community Health Centre	Hospitals
Primary Health Centre	Dispensary
Sub Centre	
Village Health Guides	

National healthcare structure in India

Centre	Population Norms	
	Plain Area	Hilly/Tribal/Difficult area
Sub Centre	5000	3000
Primary Health Centre	30000	20000
Community Health Centre	120000	80000

Recommended population under each centre

The project started out with a general study of the overall healthcare structure in India because the target user of this product is rural middle class people and ASHA workers (Village Health Guides) who are working in rural India. The ASHA worker is the most important cog in this wheel. ASHA stands for Accredited Social Health Activists and they are community health workers instituted by the Government of India's Ministry of Health and Family Welfare (MoHFW) as part of the National Rural Health Mission (NRHM).[1]

A list of their tasks include motivating women to give birth in hospitals, bringing children to immunization clinics, encouraging family planning (e.g. surgical sterilization), treating basic illness and injury with first aid, keeping demographic records, and improving village sanitation. But their most important contribution is to serve as a key communication mechanism between the healthcare system and rural populations. It is very much important to understand the context before focussing the a particular issue in healthcare. For this purpose, a preliminary study was done with short visits to certain healthcare setups and general interviews with various people associated with the

topic. Information from both book and internet publications were also gathered. The following are some important topics which will help in understanding the overall healthcare scenario in India. [1]

Government healthcare structure

The Healthcare system in the India is under a specified structure set by the central government with proper responsibilities given to the states and further to smaller administrative centres like Districts, Talukas etc.The table on the left gives an outline of the hierarchy of healthcare institutions in the country. The urban areas have enough private players and the government's role is more or less limited. However, in the rural areas, the people depend more or less solely on the government institutions for medical care. The following paragraphs elaborates the rural system.[2]

Community Health Centres (CHCs)

CHCs are being established and maintained by the State Government under MNP/BMS programme . It is staffed by four medical specialists viz. Surgeon, Physician, Gynaecologist and Paediatrician supported by 21 paramedical and other staff. It should have 30 in-door beds with one OT, Xray, Labour Room and Laboratory facilities. It acts as a referral centre for 4 PHCs and also provides facilities for obstetric care and specialist consultations. As on March, 2007, there are 4,045 CHCs functioning in the country. [2]

Sub-Centres (SCs)

The Sub-Centre is the first contact point between the primary health care system and the community. Each Sub-Centre is manned by one Auxiliary Nurse Midwife (ANM) and one Male Health Worker/ MPW(M) One Lady Health Worker (LHV)looks over six Sub-Centres. Sub-Centres are assigned tasks in relation to maternal and child health, family welfare, nutrition, immunization, diarrhoea control and control. of communicable diseases programmes.

The Sub-Centres are provided with basic drugs for minor ailments needed for taking care of essential health needs of men, women and children. The Ministry of Health & Family Welfare is providing 100% Central assistance to all the Sub-Centres in the country since April 2002 in the form of salary of ANMs and LHVs and rent, in addition to drugs and equipment kits. The salary of the Male Worker is borne by the State Governments. Under the Swap Scheme, the Government of India has taken over an additional 39,554 Sub Centres from State Governments / Union Territories since April, 2002 in lieu of 5,434 number of Rural Family Welfare Centres transferred to the State

Governments / Union Territories. There are 1,45,272 Sub Centres functioning in the country as on March 2007.[3]

Healthcare disparity in India

Public Sector

In recent times, India may have been portrayed as one of the emerging giant economies in the world. However, its healthcare infrastructure has not kept pace with the economy's growth. While India has several centres of excellence in healthcare delivery, these facilities are limited in their ability to drive healthcare standards because of the poor infrastructure in the vast majority of the country.

As per official record, India had 15,393 hospitals as of 2002, but approximately two-thirds were public which, sadly can provide only bare minimum basic services due to years of under-funding and lack of motivation. Of course there are exceptions such as the All India Institute of Medical Studies (AIIMS) but clearly most public health facilities are inefficient, inadequately managed and staffed, and have poorly maintained medical equipment.

The number of public health facilities also is inadequate. For instance, India as a country requires 74,150 community health centres per million population but actually has less than half that number. In

STAFFING PATTERN		No. of posts
A	***Sub-Centre***	***3***
1	Health Worker (Female)/ANM	1
2	Health Worker (Male)	1
3	Voluntary Worker	1
B	***Primary Health Centre***	***15***
1	Medical Officer	1
2	Pharmacist	1
3	Nurse Mid-wife (Staff Nurse)	1
4	Health Worker (Female)/ANM	1
5	Health Educator	1
6	Health Assistant (Male)	1
7	Health Assistant (Female)/LHV	1
8	Upper Division Clerk	1
9	Lower Division Clerk	1
10	Laboratory Technician	1
11	Driver (Subject to availability of Vehicle)	1
12	Class IV	4
C	***Community Health Centre***	***25***
1	Medical Officer*	4
2	Nurse Mid– Wife(staff Nurse)	7
3	Dresser	1
4	Pharmacist/Compounder	1
5	Laboratory Technician	1
6	Radiographer	1
7	Ward Boys	2
8	Dhobi	1
9	Sweeper	3
10	Mali	1
11	Chowkidar .	1
12	Aya	1
13	Peon	1

addition, at least 11 Indian states do not have laboratories for testing drugs, and more than half of existing laboratories are not properly equipped or staffed.

One of the various challenges India faces, improving access to basic healthcare is perhaps one of the most pressing - from a straightforward human development perspective as well as to ensure a solid foundation for the country's future economic growth. According to a study conducted by the Confederation of Indian Industry, the formal healthcare system reaches only about 50% of the total population. India is also desperately short of doctors, with only 645,825, or 0.6 per 1,000 people, in 2004, according to the World Health Organisation (WHO). Many locally trained physicians are tempted abroad by better pay and prospects; moreover, healthcare workers who do remain in India prefer the cities where job prospects and wages are better, resources are greater and the quality of life is far higher. [3]

Private Sector

The primary responsibility for public health funding lies with the state governments, which provide about 80% of public funding. The central government contributes another 15%, mostly through national health programs. However, the total healthcare financing by the public sector is dwarfed by private sector spending.

In the year 2003, fee-charging private firms accounted for 82% of India's $30.5 billion expenditure on healthcare. This is an extremely high proportion by international standards (by comparison, G7 countries have a proportion of about 27% and other BRIC countries have around 59%). Private firms are now thought to provide about 60% of all outpatient care in India and as much as 40% of all in-patient care. It is estimated that nearly 70% of all hospitals and about 40% of hospital beds in the country are in the private sector.

According to a joint study by the Confederation of Indian Industry and McKinsey, Indian medical tourism was estimated at $350 million in 2006 and has the potential to grow into a $2 billion industry by 2012.4 An estimated 180,000 medical tourists were treated at Indian facilities in 2004 (up from 10,000 just five years earlier), and the number has been growing at 25-30% annually. India has the potential to attract one million medical tourists each year, which could contribute $5 billion to the economy, according to the Confederation of Indian Industries.

Urban and rural divide

The exact healthcare situation may be different from state to state. For

Per Lakh population	Beds	Hospitals	Dispensaries
Urban	178.78	3.6	3.6
Rural	9.85	0.36	1.49

Source: Review of Health Care in India, 2005

example, Andhra Pradesh has a much more mature public healthcare system than UP or even Maharashtra. However, it is quite clear that the difference between rural and urban is very much consistent throughout the country. Today, only 25% of the Indian population has access to highly equipped pathologies, which are practiced mainly in urban areas, where two-thirds of India's hospitals and health centres are located. The central government has begun taking steps to improve rural healthcare. Among other things, the government launched the National Rural Health Mission 2005-2012 in April 2005.

The aim of the Mission is to provide effective healthcare to India's rural population, with a focus on 18 states that have low public health indicators and/or inadequate infrastructure. These include Arunachal Pradesh, Assam, Bihar, Chhattisgarh, Himachal Pradesh, Jharkhand, Jammu & Kashmir, Manipur, Mizoram, Meghalaya, Madhya Pradesh, Nagaland, Orissa, Rajasthan, Sikkim, Tripura, Uttaranchal and Uttar Pradesh. Through the Mission, the government is working to increase the capabilities of primary medical facilities in rural areas, and ease the burden on to tertiary care centres in the cities, by providing equipment and training primary care physicians in how to perform basic surgeries, such as cataract surgery. While the rural poor are underserved, at least they can access the limited number of government-support medical facilities that are available to them. The huge number of urban poor, who are mainly migrants from the villages fare even worse, because they cannot afford to visit the private facilities that thrive in India's cities and also lose out on the rural health schemes.

Telemedicine

Only 25% of India's specialist physicians reside in semi-urban areas, and a mere 3 % live in rural areas. As a result, rural areas,with a population approaching 700 million, continue to be deprived of proper healthcare facilities. One solution is telemedicine - the remote diagnosis, monitoring and treatment of patients via video conferences or the Internet. Several major private hospitals have adopted telemedicine services, and a number of hospitals have developed public-private partnerships among them Apollo, AIIMS,

Image 2. *Telemedicine Service in Arvind Hospital,Hubali.*

Narayana Hridayalaya, Aravind Hospitals and Sankara Nethralaya. The early successes of telemedicine pioneers have led to increased acceptance and proliferation of telemedicine. Today there are approximately 120 telemedicine centres throughout India. The Asian Heart Institute (AHI) is planning to establish 60 more telemedicine satellite centres across the interiors of Maharastra.

The government has also made a major commitment to the growth of telemedicine. The Indian Space Research Organization (ISRO) plans to establish 100 telemedicine centres across the country. ISRO has already connected 25 major hospitals in the mainland and plans to link at least 650 district hospitals by 2008. And while India has yet to pass legislation on telemedicine related issues, the Ministry of Information Technology has developed "Recommended Guidelines & Standards for Practice of Telemedicine in India," with the goal of standardizing digital communication in telemedicine. The Medical Council of India has formed committees to explore this and other legal aspects of telehealth. There is a growing movement within India to establish a health grid that connects medical institutions and practitioners throughout the country. This would allow super specialists to exchange case studies, compare experiences, and hold virtual conferences to discuss critical disease patterns and provide treatment.

Vaatsalya

Another notable idea put to action is the Vaatsalya chain of hospitals. While 70% of India lives in semi-urban and rural areas, 80% of India's healthcare facilities are located in urban areas. The idea of creating a chain of good hospitals at low cost was in 2004 and came to Ashwin Naik, the current CEO of Vaatsalya.

Vaatsalya is a semi urban only hospital chain aimed at bridging the gap between urban and the rapidly increasing semi urban areas by building and managing hospitals and bringing healthcare services. where it is needed most. Vaatsalya is India's first affordable hospital

Image 3. *Vaatsalya Hospital, Hubali..*

network focused on Tier II and Tier III towns. Vaatsalya Hospitals provide primary and secondary care services with emphasis on prevention. Specialties at each hospital include paediatrics, gynaecology, medicine, and surgery. In addition we are leaders in providing dialysis services across Karnataka With their mission of "Affordable, Accessible and Appropriate", they work to provide healthcare services to thousands of families across Karnataka and Andhra Pradesh through our hospitals in Hubli, Gadag, Bijapur, Mandya, Raichur, Hassan, Mysore, Gulbarga, Shimoga, Vizianagaram (AP) and Narasannapetta (AP).

It is not only a very philanthropic service but also a very clever and sound business model. Vaatsalya will reach break even by 2011. It demonstrates the scalability of a business model based on rents and lower wages in the towns of medium size. It hires the best doctors and are equipped with excellent infrastructure.

User Study and Places Visited

Image 6. *PHC Uchgaon*

Image 7. *Military Hospital, Belgaum..*

Image 8. *City hospital outdoor blood collection Center, Belgaum..*

Image 9. *Active Blood checkupcamp, Majgaon*

Image 10. *Active blood checkup camp, Majgaon*

1. Hindalaga - Belgaum

2. Uchgaun - Belgaum

3. IIT Bombay Hospital

4. Hinduja Hospital, Mumbai

5. Hiranandani Hospital, Mumbai.

Visit to Hindalga and Uchagaon

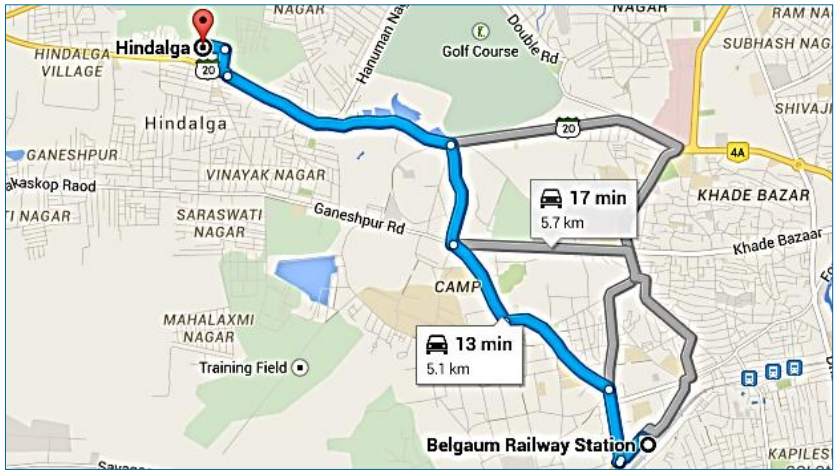


Image 11. *Way to Hindalga from Belgaum city*

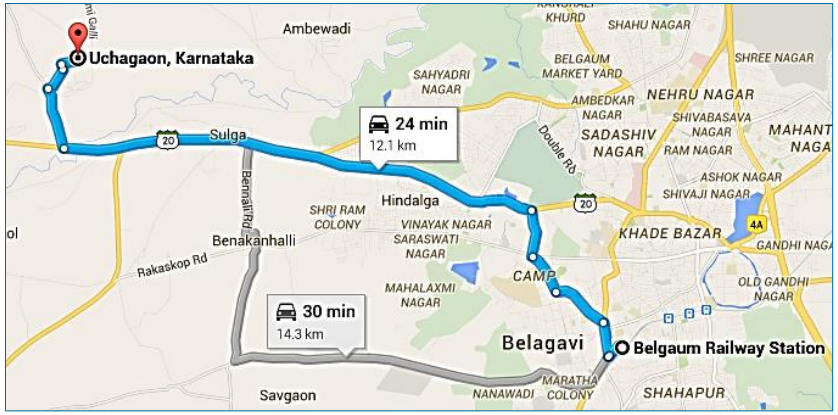


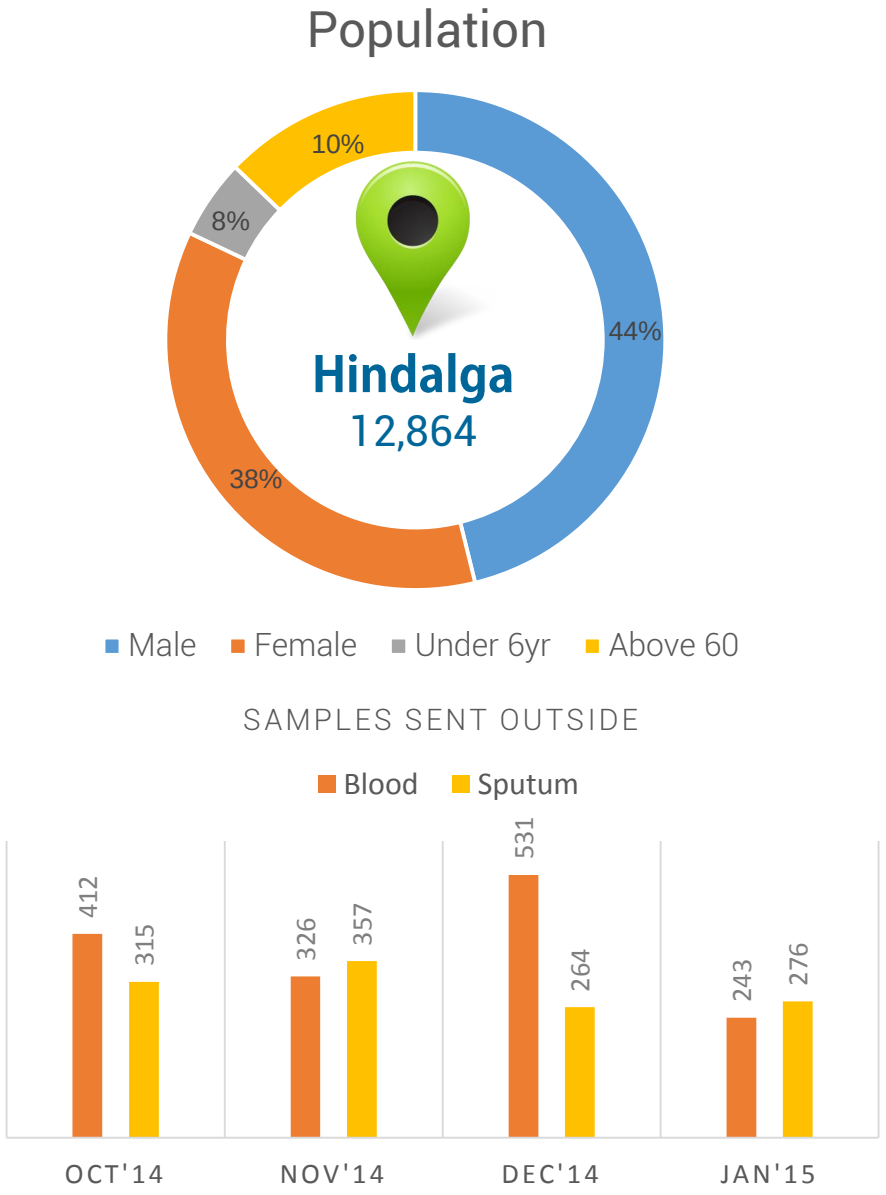
Image 12. *Way to Uchagaon from Belgaum city*

https://www.google.co.in/maps/dir/Belgaum,+Karnataka/Hindalga,+Belgaum,+Karnataka+591108/@15.8617321,74.4807385,15z/data=!3m1!4b1!4m13!4m12!1m5!1m1!1s0x3bbf669f5095362f:0x7e34b31edcdefb5f!2m2!1d74.4976741!2d15.8496953!1m5!1m1!1s0x3bbf63f5a1c68b53:0xa7e1e22d86c87099!2m2!1d74.4800383!2d15.8736274

As part of data collection, a visit was made to Hindalga and Uchagaon, which has a good mix of both rural and semi urban conditions. At two hours drive from Belgaum, Karnataka, it is an ideal place of investigation for my project. Collected many administrative level information on the present healthcare condition in the town. Lots of grassroot information were also gathered from interaction with a local NGO called Ganesh Mandal and from representatives of Disha Kendra, which acts as a nodal source for information in the town. Population of hindalga is

Hindalga has 2 PHC's. The PHC's are located at the surrounding villages of Sulaga, Mannur and Ambewadi. In the town area, around 4 private clinics have come up. Uchagaon has 3 PHC's and a sub-district hospital. The PHC's are located at the surrounding villages of Kallehol and Konewadi. In the town area, around 6 private clinics have come up.

The main purpose of the visit to these places was to visit PHC's and collect the information about the blood tests carried out monthly . The process of blood test, interaction with people from PHC's and the



Patients visiting. Lot of interesting insights were found during this visit. The statistical data found from these two visits are shown in the graph at left side. The Population of hindalga is 12,864 (according to the census of 2011.). When visited to PHC following information they gave. 38% male, 44% female, 8% under 6 years and 10% above 60 age people. PHC person showed his blood sample resister after requesting. The following insights got from that resister.

- Due to unavailability of microscope this PHC is sending daily almost 12 blood samples and 10 Sputum samples in the city hospital for diagnostic.
- The person collecting the blood sample was a pathologist , and in the absence of the microscope could not test the sample on the spot.

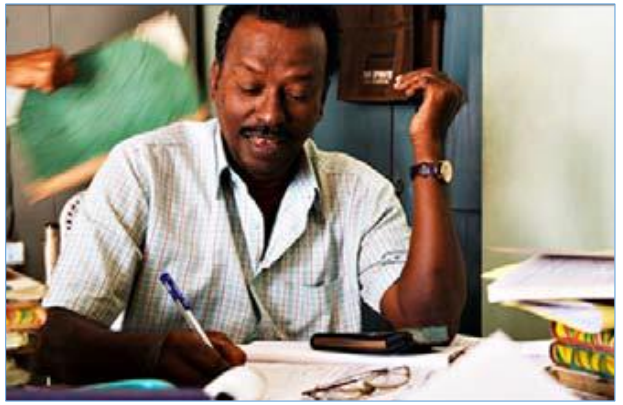
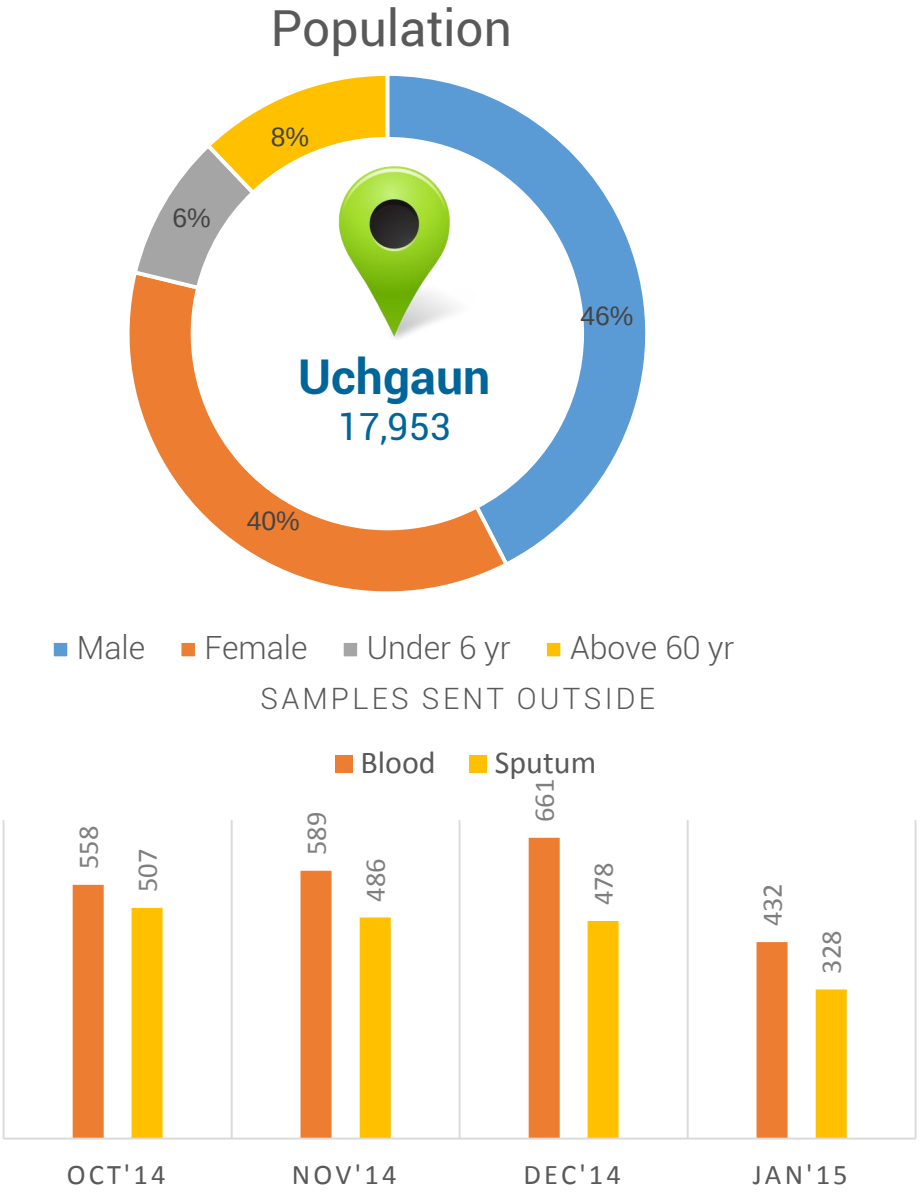


Image 13. *Pathologist in PHC Hindalga.*



- The report is available after 2 days from the blood given for test.
- In case of urgency , a helper is sent to the city diagnostic center with the sample.

The Population of Uchgaon is 17,953 (according to the census of 2011.) . The condition of PHC is same as of Hindalaga. Daily 10 blood samples and 10 samples of sputum they are sending to city diagnostic center,Belgaum. The photo(image 15) is the Blood sample register which is used by the investigator and the lab technicians to keep track of the cases served. The left photo (image 14) is the actual stained blood sample slides which are coded properly to keep a track in resister.

Image 14. *Coded blood slides.*

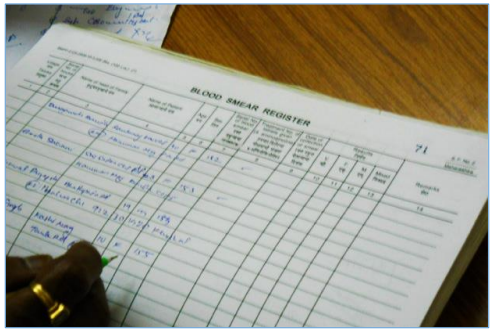


Image 15. *Blood sample register in PHC,Uchgaon.*

Visit to Pathologies

Image 16. *Hiranandani Hospital*

Image 17. *IITB Hospital*

As a part of primary research visited 3 pathologies around IIT.

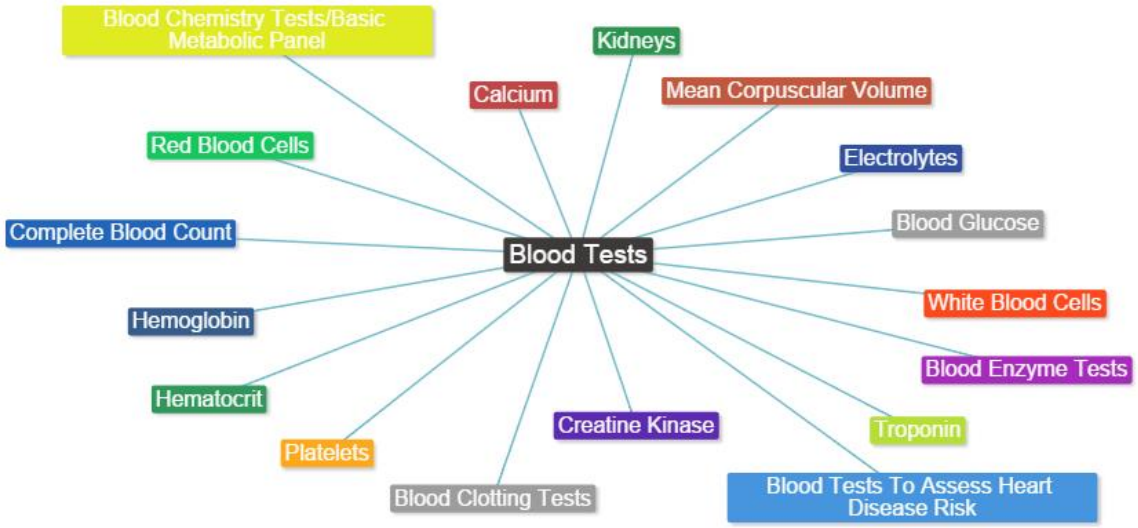
1. Hiranandani Hospital.
2. Hinduja Hospital.
3. IIT Hospital.
4. Sangeevani Pathology.

Just to see and observe the pathology activities, different blood tests and mainly to interact with the pathologists.

Image 18. *Hinduja Hospital*

http://www.magicbricks.com/Mahim-in-Mumbai/photos/Hospitals-Pharmacy-in-Mahim/PD-Hinduja-National-Hospital-photoId-4d42323137303737

Blood Tests



1. **CBC**
2. **RBC**
3. **WBC**
4. **Platelet count**
5. Hemoglobin
6. Mean Corpuscular volume
7. Basic metabolic Panel
8. Blood glucose
9. Electrolysis
10. Blood enzyme test
11. Blood clotting test
12. Troponin

After meeting lot of doctors and people around the diagnostic center, came to know that first 4 tests are carried out under 10x,40x and 100x magnification.

Activity analysis

Image 19. *Patient comes to the pathology*

Image 20. *Patient data is recorded*

Image 21*. Blood smear is taken*

Image 22 . *A receipt of the test is given to the patient*

Image 23*. The staining is done*

Image 24*. The diagnosis is done on the same day if possible*

Passive surveys are done in the pathologies visited. From Sanjeevani diagnostic center, Powai clicked some process photos and interacted with the pathologist. The basic qualification for diagnosing blood slides is the CMLT or DMLT. With so few qualified people in the government establishment, the load on the available people is tremendous as they have to cater to other sorts of duties as well. The process is much more efficient than active survey, but the same technician also caters to other patients like TB and typhoid patients. He/she also diagnoses the slides coming in from the active survey. On a normal day, around 40-50 slides are required to be tested. The number increases quite a lot during monsoon season of June and July. The the sequence of sub activity during the process cycle of active survey is listed below.

1. Patients come in pathology .
2. The lab technician takes the blood smear
3. The patient is instructed to come the next day
4. The technician is responsible for staining and diagnosis of the sample
5. The report is given to the patient with required medication

Components required for blood film test

Image 25. *Blood strainer A*

Image 26. *Blood strainer B*

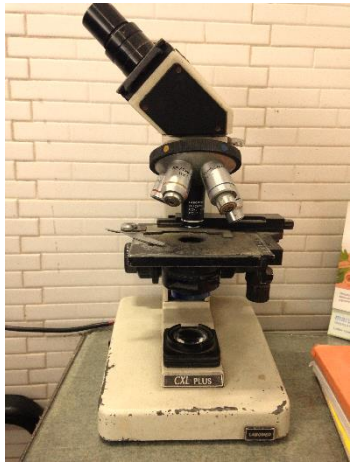


Image 27. *Microscope*

The basic necessary components required for carrying out a a blood film test are described below:

1. Stains: Stain A and stain B

2. Water

3. Methanol (for thin film)

4. Slides: Standard glass slides of 75mm by 25 mm with an a thickness of 1mm.

5. Blood smears

There are two kinds of blood smears, viz thin film and thick film. The staining process for these two kinds of films are slightly different and also the diagnostic properties.

6.Microscope

The general specifications of the microscope used is 100x, Oil immersion and Abbe condenser

Staining process activity analysis

Staining of the thick film and the thin film follows a slightly different process. The following sequence of images illustrates the staining process for both thick and thin film blood smears.

Image 28. *Finger stick puncture by using a sterile safety lancet*

Image 29. *Blood drop collection on a slide and spread over it.*

Image 30. *Deep that slide in strainer B first*

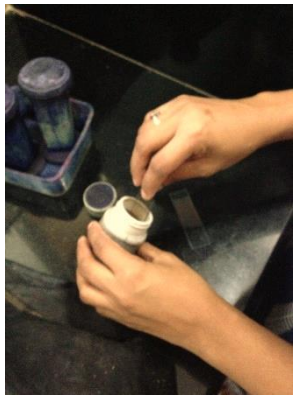


Image 31. *After washing under water deep it in a strainer A*

Image 32. *Again wash it under water and let the slide dry.*

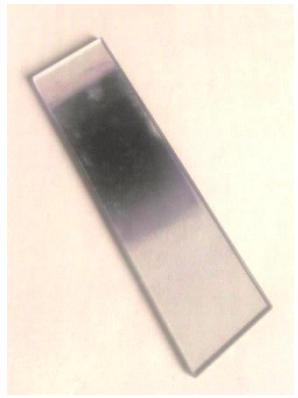


Image 33. *Stained slide is ready for diagnostic. under microscope.*

Observations

1. Village health guides and ASHA workers walks almost 15km daily to collect blood samples in Hindalaga and Uchgaon without any proper collection kit.
2. Collected slides are sent to the city hospital for diagnostics.
3. The report is then personally collected from city hospital which takes almost 2 days. Sometimes it takes 3-4 days.
4. Blood film test most feasible and reliable in city area.
5. Very acute shortage of skilled personnel
6. Coverage by govt. workers much lower than targets
7. Redundant data entry
8. Bulky kit for investigators to carry
9. Overload of work on lab technicians
10. Skill level required for microscopy is very high
11. Lack of incentive for surveillance investigators

Insights

1. An easy to use diagnostic system required.
2. Need a more light weight, compact and precise kit.
3. There is a need to streamline the communication among patients, investigators, doctors and labs.
4. Making blood film test most economical and most feasible for mass application
5. Maintenance of data and its accessibility can be improved
6. Should make provision for using lower skilled manpower in the diagnosis process
7. Provision for motivation in the system itself is required.
8. Fast delivery of reports is required.

Design Brief

“Design and develop a lab on smart phone platform that aim to implement multiple telemedicine related functionalities on smart phone, which can potentially improve the diagnostic system, health care report delivery and help reducing the cost of bio medical tests, even at remote locations of India”.

Image reference as seen on : 30/02/2015 : http://www.clipartlord.com/category/home-clip-art/appliances-clip-art/mobile-phones-clip-art/smartphone-clip-art/

Design Approach

- Problem Identification
- Literature study/ Market Study
- User Study
- Experimental Study
- Prioritizing information
- Concept Generation
- Concept Evaluation
- Concept Improvisation
- Finalizing the Concept

Problem Identification

Image 28. *Millitry Hospital,Belgaum*

Blood and sputum tests are the most common test panels ordered, yet advance hematology analyzers and appropriate laboratory infrastructure are absent or limited in most of the locations in India

This smartphone based microscopy platform can measure the density of red and white blood cells as well as hemoglobin concentration in human blood samples and may be used to identify an active tuberculosis (TB) infection by AFB test.

Literature study/ Market Study

After deciding microscopy via smartphone the market study is divided into two parts

1.Smartphone market study.

2. Microscope market study.

For smartphone market study Visited 3 mobile markets to see which type of smartphones are available in market and parallel under literature study studied the evolution of smartphone, important parts of smartphone, towards project mainly the camera module and LED module.

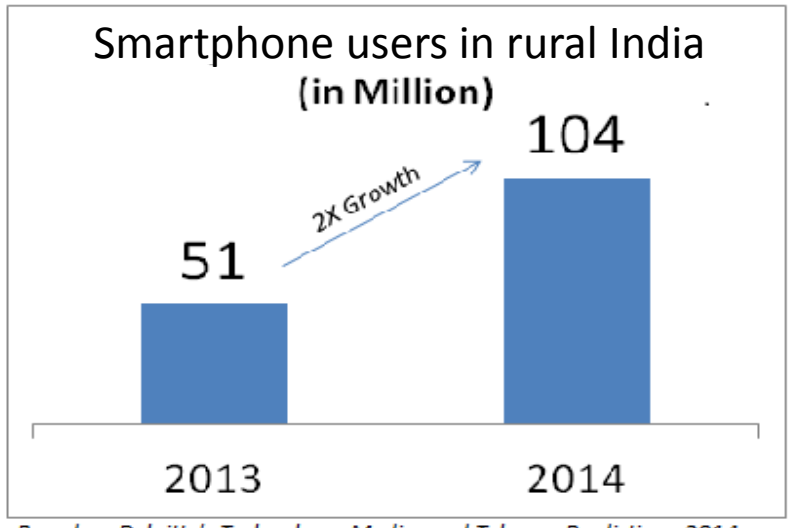
In Microscope market study, visited 2 shops near CST, Mumbai. Lots of types of microscopes are available in the market. Right from 10000Rs to 100000Rs. Same as smartphone literature study, studied microscope evolution, lens ,parts of the microscope and etc..

Smartphone and Need

Today there are approximately 7 billion cellphone users in the world, with a mobile phone penetration rate of ~96% globally. In recent years, there has also been a significant increase in smartphone use especially in the developed parts of the world, which is projected parts of the world, which is projected to reach ~40% worldwide by 2015. Driven by this rapid growth of the mobile market, the cost of the cellphone has specifically decreased despite dramatic advance in the software and hardware components of these mobile technologies. To this end, the state of art digital components embedded in cellphones, including image sensors, micro-processors, displays, communication units etc., can be employed to create new opportunities for health monitoring in both the developed and the developing regions of the world. Therefore, cellphones, with there built-in features and global connectivity, can be ubiquitous platform for biomedical imagining, sensing and diagnostics applications. which can potentially improve the health care delivery and help reduce the cost of biomedical tests world-wide by enabling the penetration of advanced microanalysis tools to even remote and resource-limited locations.

Smartphone user penetration rate in India

Today 7 billion smartphone users in the world with ~40% growth. (1)



Based on Deloitte's Technology, Media, and Telecom Predictions 2014.
http://brandalyzer.wordpress.com

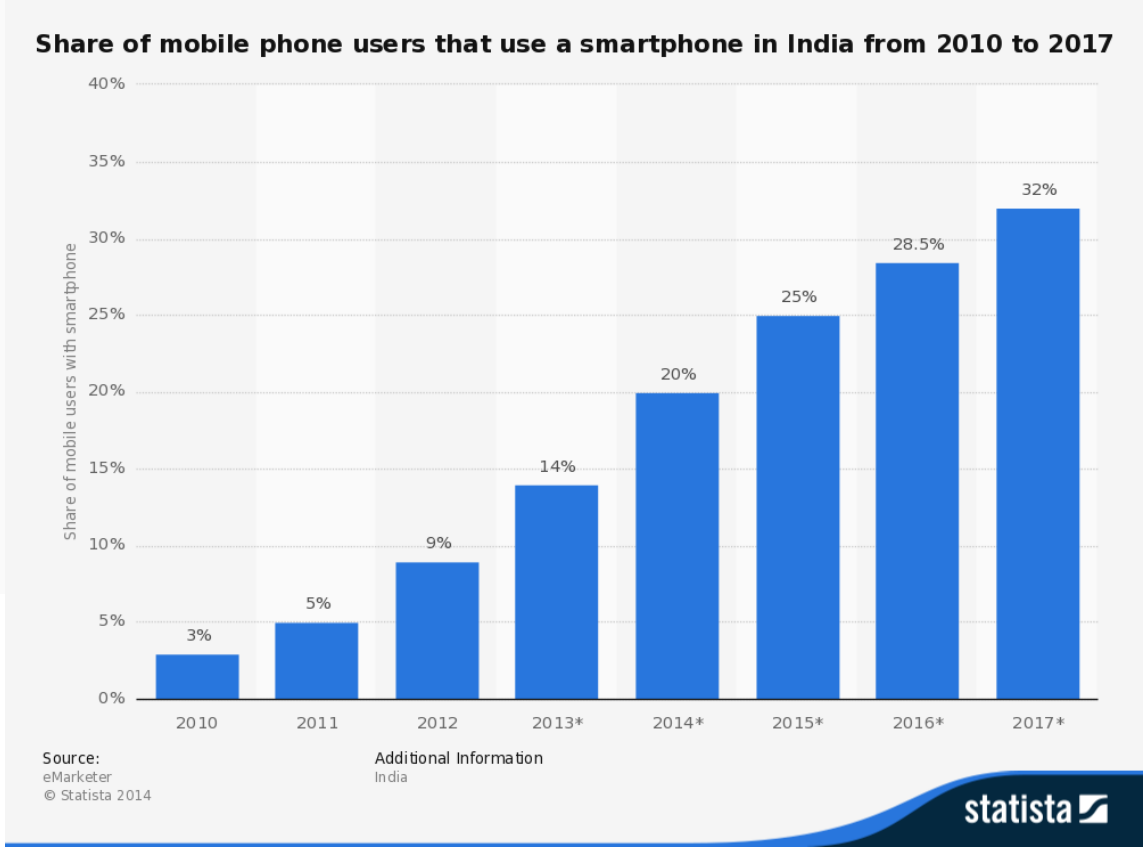


Image 29. *Penetration in India*

Smartphone Evolution

Image 30. *Smartphone Evolution*

Image reference : As seen on 22/01/2015 : http://www.movdata.net/smartphone-png.html

Parts of Smartphone

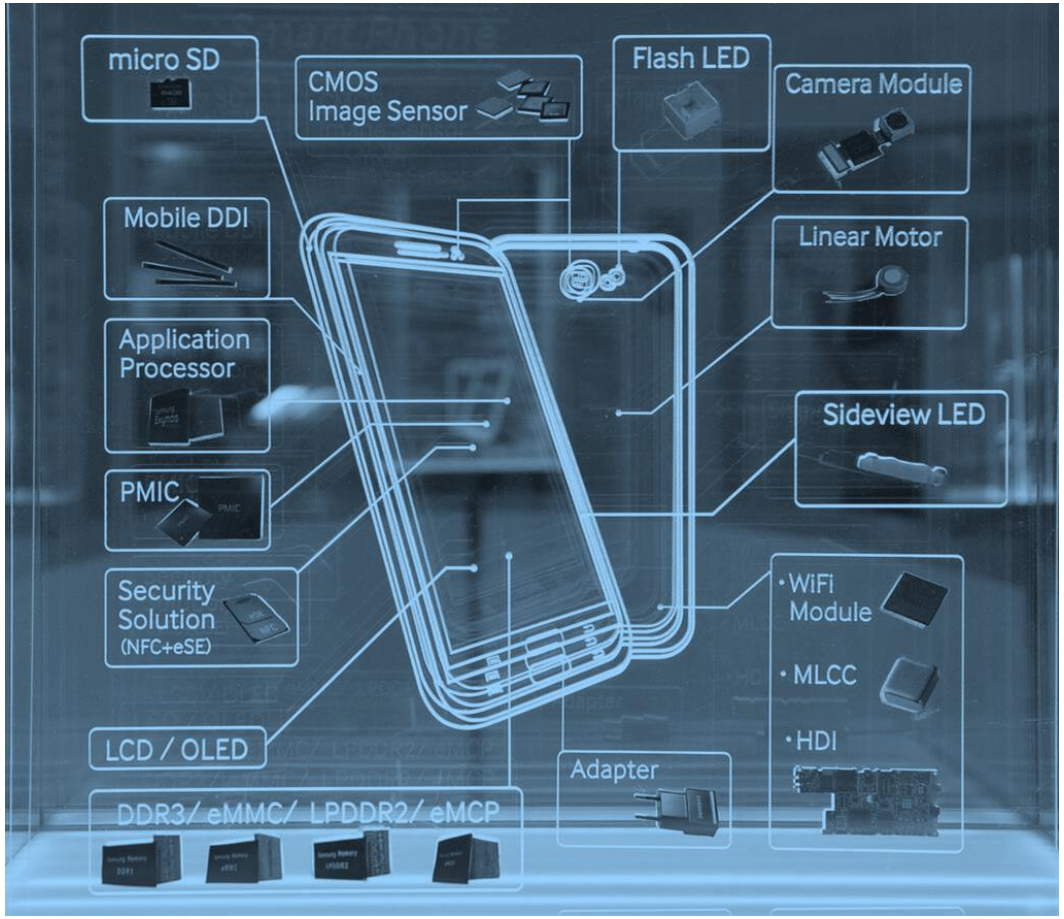


Image 31. *Parts of Smartphone*

Image reference : As seen on 29/01/2015 : http://www.itproportal.com/2013/03/18/samsung-galaxy-s4-were-17-parts-manufactured-inhouse/

The smartphone is consist of lot of small tiny parts. But the main parts of any smartphone are

1. Micro SD
2. Mobile DDI
3. Application Processor
4. PMIC
5. Security solution
6. LCD / OLED
7. Adaptor
8. Wifi module
9. Slid view LED
10. Linier Motor
11. **Camera Module**
12. Flash LED

For this project interest in area of smartphone parts are camera module. On next page entire description about camera module is given.

Camera module of Smartphone

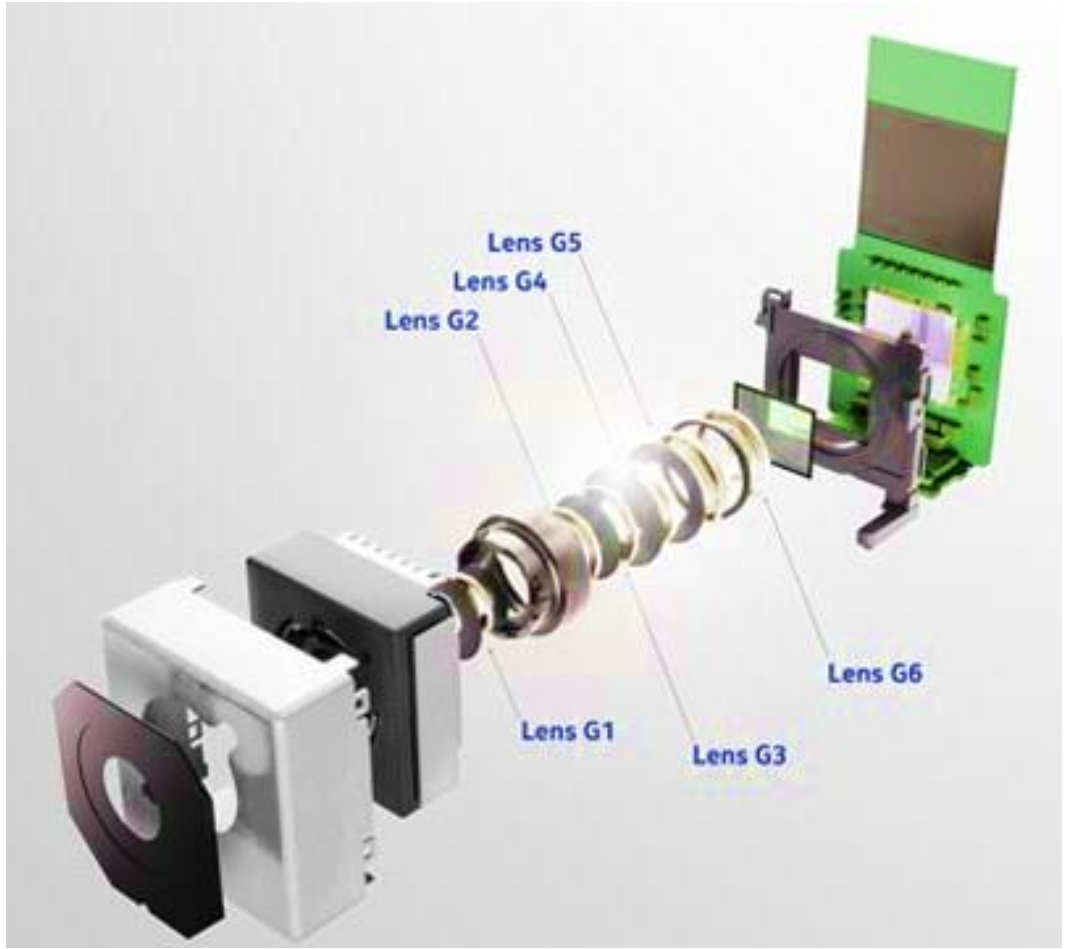


Image 32. *Camera Module*

http://www.arducam.com/category/camera-module-demonstration/

A typical camera module of smartphone is consist of very tiny sub parts and they are as follows

1. Outer casing
2. Lens holder
3. Lens G1
4. Lens G2
5. Lens G3
6. Lens G4
7. Lens G5
8. Lens G6
9. Sensor
10. Microcontroller circuit

These tiny parts plase very important role in captureing an image very clerly.

Now this project is basically based on the lens technology and the alternatives for the lense. An add on devise which will fit on a smartphone and via smartphone camera module we can control this devise.

Smartphone market study.

Apple iPhone 4s	Nokia Lumia 800	Google Galaxy Nexus	Samsung Galaxy S II	HTC Evo 4G	Samsung Galaxy S II	Samsung Galaxy Note	Sony Ericsson Xperia
115.2 x 58.66 x 9.3 mm	116.5 x 61.2 x 12.1 mm	135.5 x 67.94 x 8.94 mm	130.9 x 69.9 x 9.4 mm	122 x 66 x 12.7 mm	129.8 x 68.8 x 9.5 mm	145.8 x 82.95 x 9.65 mm	119 x 63 x 13 mm
4.54 x 2.31 x 0.37 in	4.59 x 2.41 x 0.48 in	5.33 x 2.67 x 0.35 in	5.15 x 2.75 x 0.37 in	4.8 x 2.6 x 0.5 in	5.11 x 2.71 x 0.37 in	5.74 x 3.27 x 0.38 in	4.69 x 2.48 x 0.51 in
140 gr / 4.94 oz	142 gr / 5.01 oz	135 gr / 4.76 oz	132 g / 4.66 oz	170 g / 6 oz	130.5 g / 4.6 oz	178 g / 6.28 oz	135 g / 4.76 oz
3.5" screen	3.7" screen	4.65" screen	4.5" screen	4.3" screen	4.65" screen	5.3" screen	4" screen
640x960px	480x800px	720x1280px	480x800px	480x800px	720x1280px	800x1280px	480x854px
~330 ppi	~252 ppi	~316 ppi	~207ppi	~217ppi	~316ppi	~285ppi	~245ppi

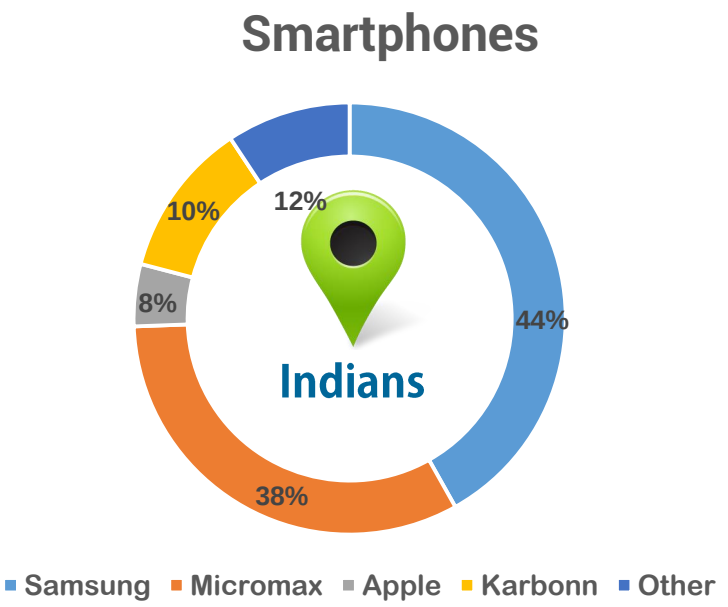
Image 33. *Smartphone market study*

http://www.cnet.com/news/smartphone-market-share-consolidates-at-top-study-shows/ as shown in jfr 23/04/2015

Smartphone user study.

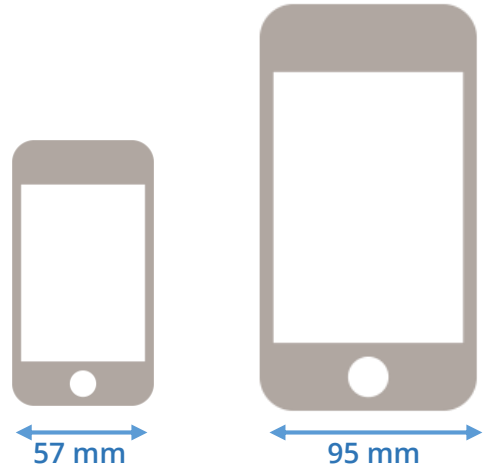
Image 34. *Users using smartphone*

Insights from smartphone user study



Smartphone user study carried out in following 12 places. Almost 389 Users were asked to show their smartphone to see which mobile phone they are using and how many megapixel camera phone they are using.

1. Bhandup
2. Borivali West
3. Thane
4. Andheri East
5. Andheri West
6. Bandra
7. Dadar
8. Chembur
9. Colaba
10. Kolhapur
11. Belgaum
12. Pune



One google form was also floated on the email thread and on social media sites in order to know the mobile phone users preference towards smartphone mobile brand and how much camera mega pixel they prefers. The insight got from the smartphone user study is shown in matrix format in fig. form it over 44% people are using Samsung,38% are using Micromax, 8% are using Apple,10% are using Karbonn and over 12% people are using other brand like Sony, Nokia, HTC etc.

The range of megapixel camera they are using is 5 MP to 12 MP. The width of smallest smart phone available in the market is 57mm and that of biggest is 95mm.

Inspiring Product

NETRA is an award winning mobile eye diagnostic device developed at MIT Media Lab consisting of a clip-on eyepiece and a software app for smart phones. It can be seen as the inverse of expensive Shack-Hartmann sensors. NETRA allows for the early, low-cost diagnosis of the most common refractive Refractive Disorders. The subject looks into the device and aligns patterns on the display. By repeating this procedure for eight meridians, the required refractive correction is computed.

Image 35-39. *Netra project, MIT USA*

Parallel Product Study

There are some products in market which are add-on features to smartphone. But these add-on devices are their only for photography purpose not for diagnostic or medical use. The maximum magnification value of these devises is 8x magnification.

The typical photos on the extreme left bottom are the direct use of smartphone on microscope. These are used to zooming in and zooming out of the object placed under the microscope.

Image 40-44. *Add-on lenses for photography available in market*

Images reference : As seen on: 29/01/2015 : http---kartrocket-mtp.s3.amazonaws.com-all-stores-image_gadgetstuff-data-ML_FishEyeLens_001

A Brief History of Microscope

Image 45. *Microscope inventers*

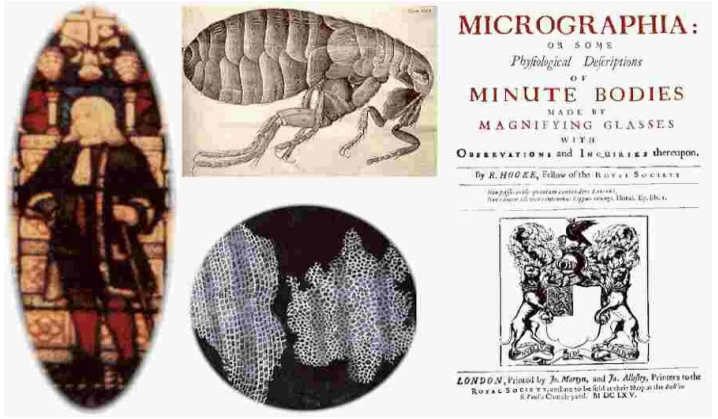


Image 46. *Advertise of microscope in 1872*

Credit for the first microscope is usually given to Zacharias Janssen, pictured at the left, in Middleburg, Holland, around the year 1595.
The first compound microscopes produced by the Janssen's was simply a tube with lenses at each end.
The magnification of these early scopes ranged from 3X to 9X, depending on the size of the diaphragm openings.

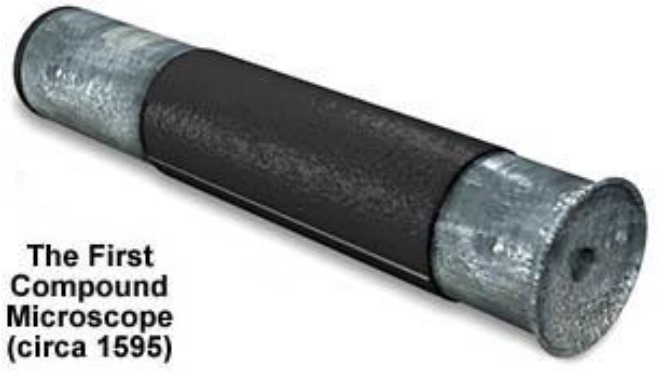


Image 47. *First microscope*

Image reference as seen on 25/01/2015 : http://www.cas.miamioh.edu/mbiws/microscopes/fathers.html

Microscope evolution contributors

Egyptians	~2600 B.C.E.	Rock crystal artifacts found in the shape of convex lenses
Greeks and Romans	~31 C.E.	Observed the magnification properties of water, used rock crystal convex lenses, practiced glass blowing
Arabian Alhazen	(962 - 1038 C.E.)	Described the actions of the lenses in his treatise on optics called Optics Thesaurus Alhazeni Arabius Basil
Roger Bacon	(1214-1292 C.E.)	Referred to the concepts and usages of lenses in his scientific works
Ernst Leitz	1873 C.E.	Introduced mircoscope with revolving nosepiece for objectives
August Kohler	~1880 C.E.	Figured out the optimum spacing for the light and condenser which would produce sharp images
Katherine Blodgett	1917 C.E.	Developed micro-coatings which allowed her to develop non-reflecting "invisible" glass
Max Knoll and Ernst Ruska	1931 C.E.	Built the first electron microscope
Ernt Ruska	1933 C.E.	Increases magnification of electron microscope to levels higher than a compound light microscope

Nikon, one of the world's largest manufacturers of microscopes and cameras, made this microscope in the early 1900s. The compound monocular microscope is fashioned from brass and has a black-enameled horseshoe base.

Image 48. *Nikon's first microscope*

Image reference as seen on 22/01/2015 :
http://www.microscopyu.com/museum/firstnikon.html

Image reference as seen on 21/01/2015 : http://www.dreamstime.com/royalty-free-stock-images-green-microscope-image22544559

Parts of Microscope

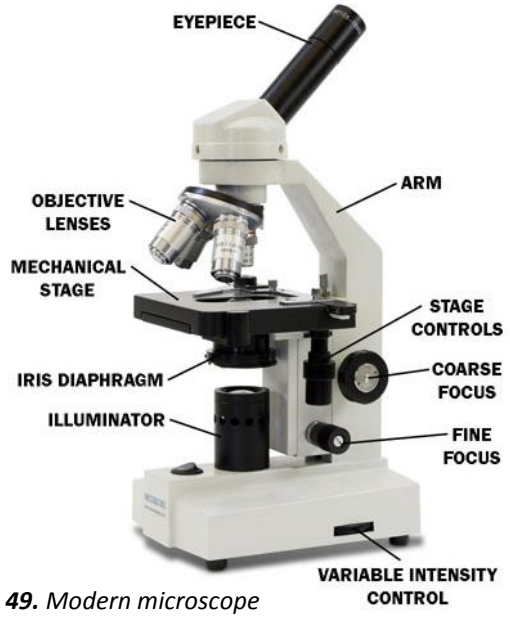


Image 49. *Modern microscope*

Image reference : as seen on 22/01/2015 http://woomyoung.co.kr/product_view.html

The simplest optical microscope is the magnifying glass and is good to about ten times (10X) magnification. The compound microscope has two systems of lenses for greater magnification, 1) the ocular, or eyepiece lens that one looks into and 2) the objective lens, or the lens closest to the object. Before using a microscope, it is important to know the functions of each part.

Eyepiece Lens: the lens at the top that you look through. They are usually 10X or 15X power.

Tube: Connects the eyepiece to the objective lenses

Arm: Supports the tube and connects it to the base

Base: The bottom of the microscope, used for support

Illuminator: A steady light source (110 volts) used in place of a mirror.

Stage: The flat platform where you place your slides.

Revolving Nosepiece or Turret: This is the part that holds two or more objective lenses and can be rotated to easily change power.

Objective Lenses: Usually you will find 3 or 4 objective lenses on a microscope. They almost always consist of 4X, 10X, 40X and 100X powers.

Rack Stop: This is an adjustment that determines how close the objective lens can get to the slide.

Condenser Lens: The purpose of the condenser lens is to focus the light onto the specimen.

Diaphragm or Iris: To vary the intensity and size of the cone of light that is projected upward into the slide.

Simple and block Diagram of a Microscope.

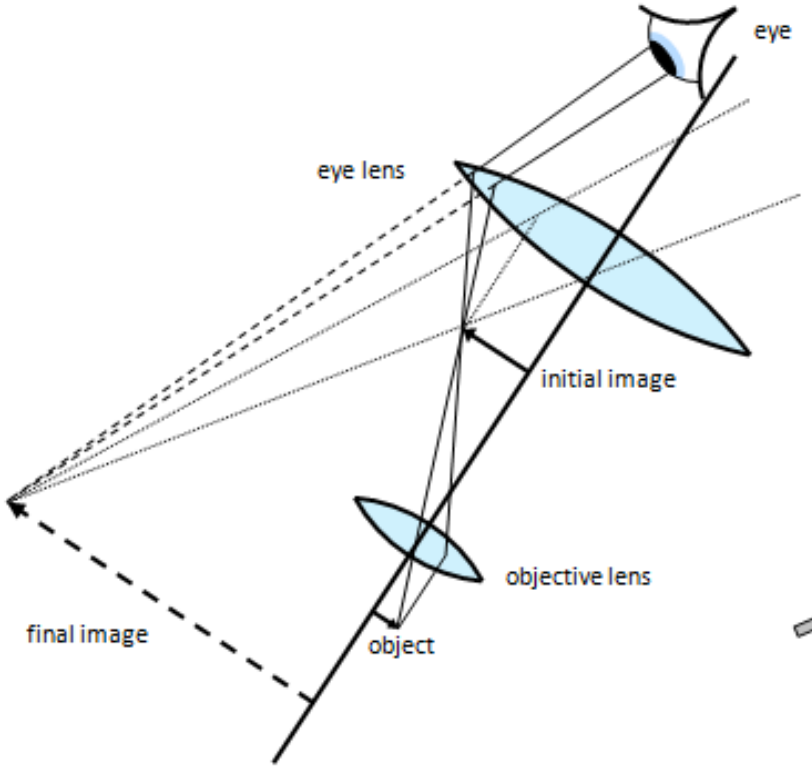


Image 50. *Optical diagram of Microscope*

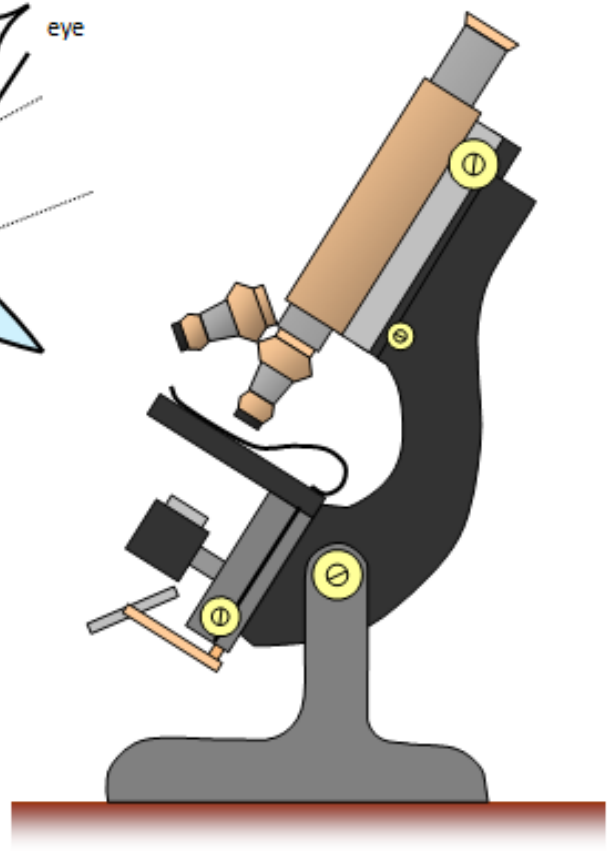


Image 51. *Microscope Body*

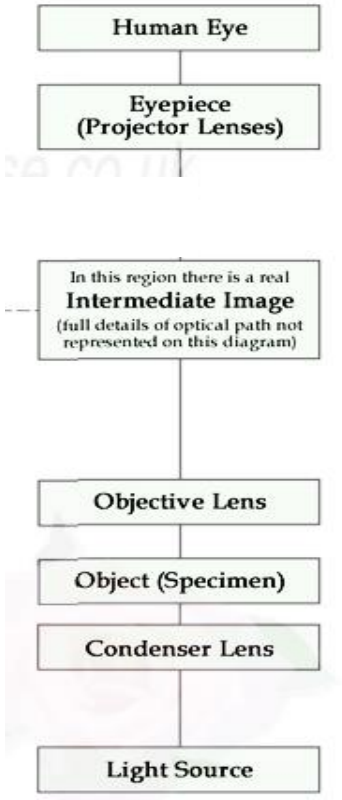


Image 52. *Block diagram of Microscope*

Image reference seen on 22/01/2015 : http://www.ivyroses.com/Biology/Techniques/Light-Microscope.php

Optical physics of a Microscope.

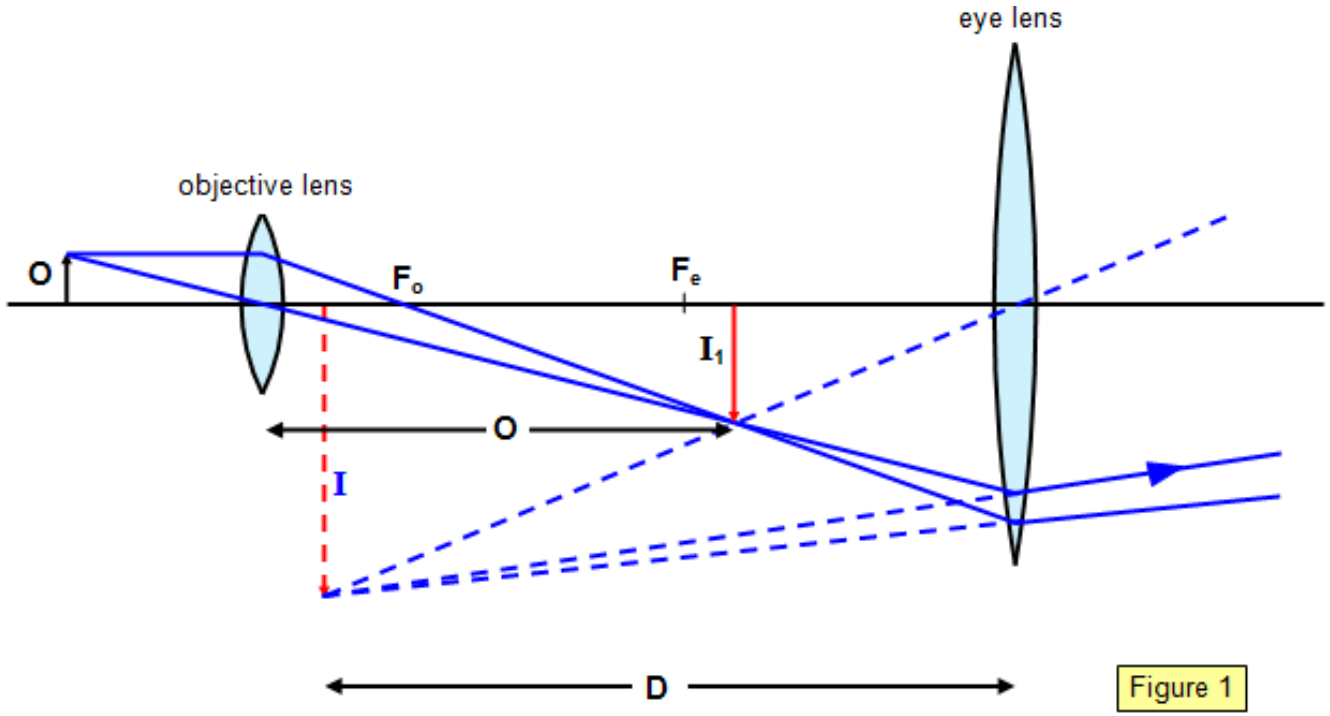


Image 53. *Ray and lenses in Microscope*

Image reference seen on 22/01/2015 : http://www.ivyroses.com/Biology/Techniques/Light-Microscope.php

$$\text{Magnifying power (M)} = [D/f_e - 1][v/f_o - 1]$$

Where f_e is the focal length of the eye lens, f_o that of the objective lens and v the distance of I_1 from the objective lens.

Study of Blood cell vs mobile resolution

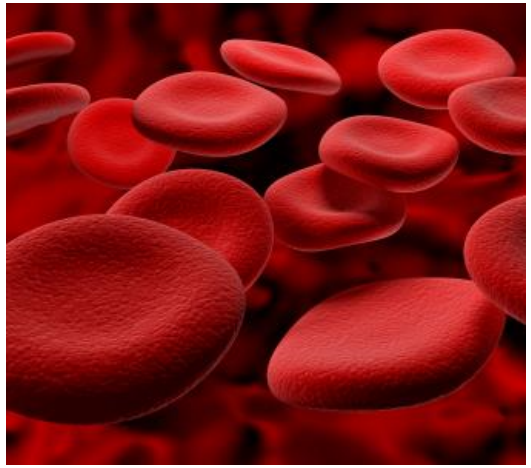


Image 54. *Red Blood Cells*
http://www.slideshare.net/problemloeser/2012-mob-xaxureworkhopforslideshare

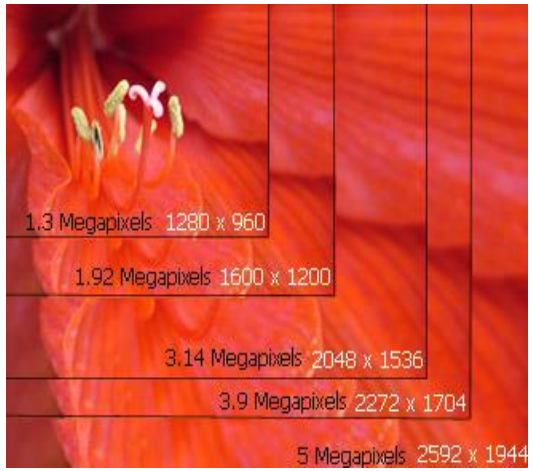


Image 55. *Diff. Sizes of Smartphone resolution*
http://www.slideshare.net/problemloeser/2012-mob-xaxureworkhopforslideshare

The size of red blood cells usually falls within a range of 6 to 8 micrometers in random blood samples that have been analyzed by laboratory testing. Mature forms of the red blood cells (RBCs) are called erythrocytes, which constitute around 40 to 45% of human red blood cells. Immature forms of red blood cells are termed reticulocytes, and these usually account for only about 1 to 2% of the red blood cells.

The pixel (a word invented from "picture element") is the basic unit of programmable color on a computer display or in a computer image. Think of it as a logical - rather than a physical - unit. The physical size of a pixel depends on how you've set the resolution for the display screen. If you've set the display to its maximum resolution, the physical size of a pixel will equal the physical size of the dot pitch (let's just call it the dot size) of the display.

So from above information it is clear that the blood cells can be visible on the mobile screen with minimum resolution size that is 1280 * 960 that is 1.3 Megapixels.

Actual oil emersion lens study

Image 56-59. *Different views of Oil emersion lens*

To study the lens technology behind microscope the oil emersion lens is purchased from market and studied. In light microscopy, oil immersion is a technique used to increase the resolution of a microscope. This is achieved by immersing both the objective lens and the specimen in a transparent oil of high refractive index, thereby increasing the numerical aperture of the objective lens.

Test rig for SmartScope.

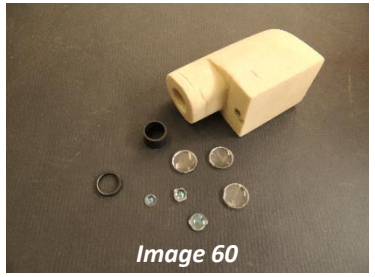


Image 60

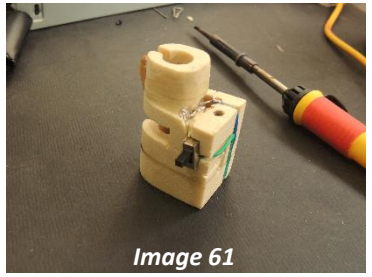


Image 61


Image 62


Image 63

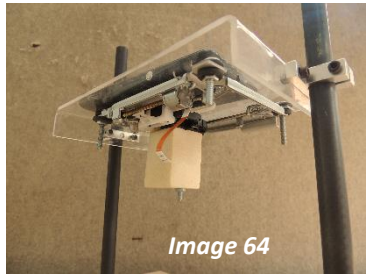


Image 64

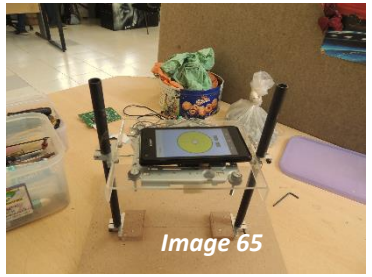


Image 65

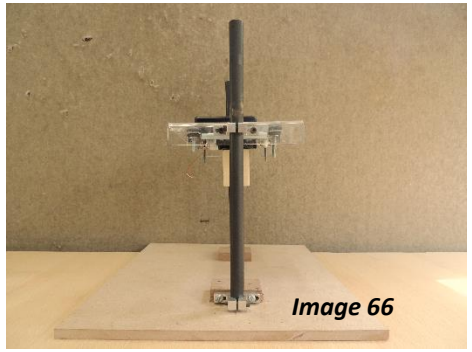


Image 66

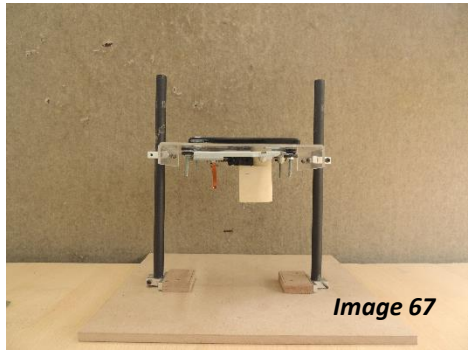


Image 67

Image 60-67. *Test rig of smartphone microcopy*

After studding the lens technology of microscope oil emersion lens made one test rig in which following components were used.

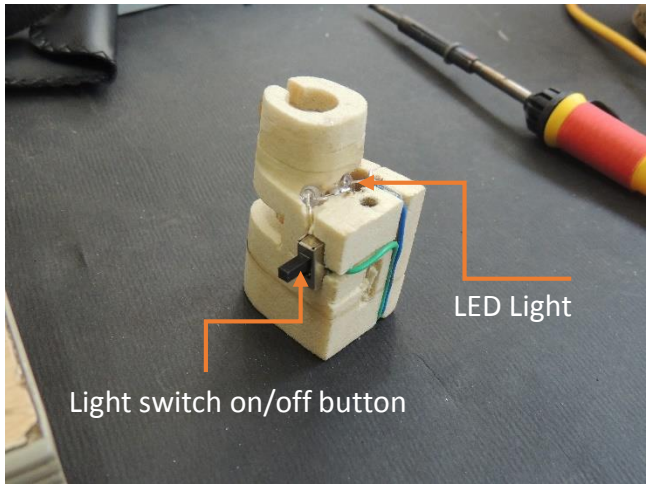
1. lenses having diameter 0.9 cm (3 nos)
2. LED (2 nos)
3. AAA size power cell
4. On/off switch

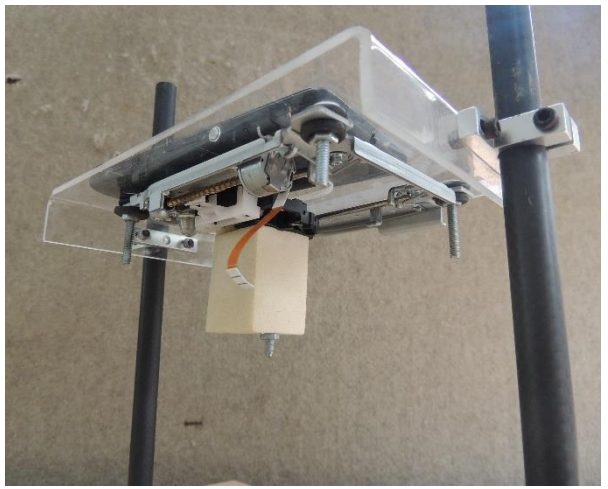
Above all components are placed in the PU foam model as shown in image no 61 This test rig is made for dimensioning the lens height adjustment and to study which height giving how much magnification.

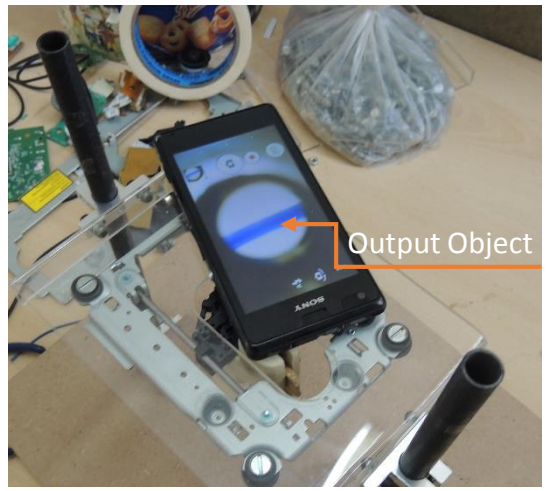
After placing all 3 lenses each at 2mm distance the highest magnification value getting is 40x.

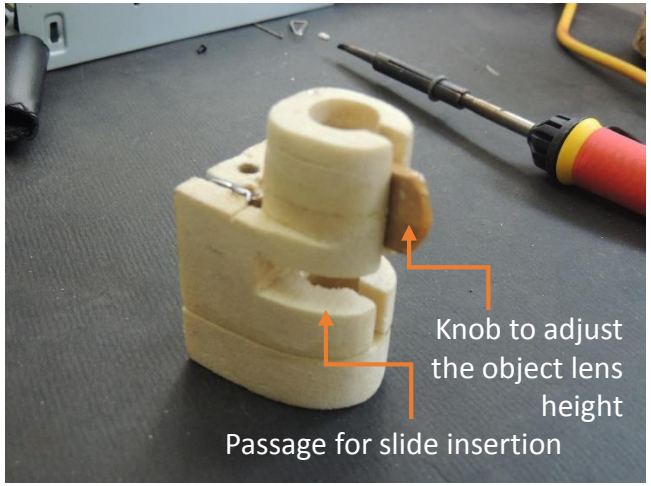
One more reson behind making this test rig is to study the images from all types of resolutions of mobiles available around. Range is from 2MP to 12MP.

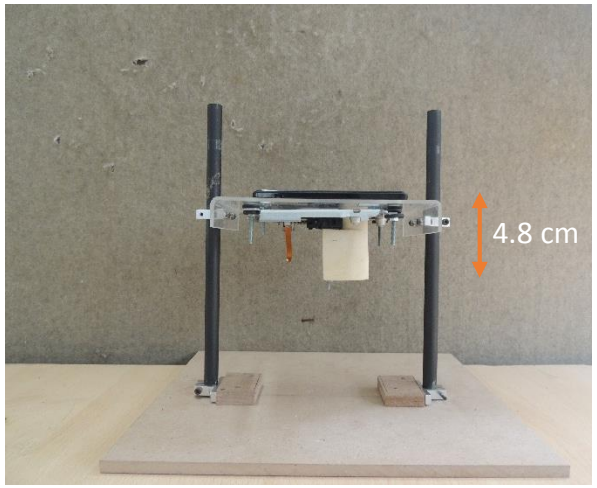
Test rig Detailing.











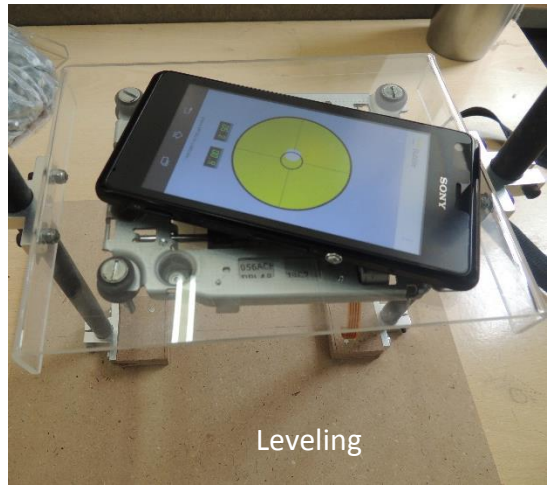
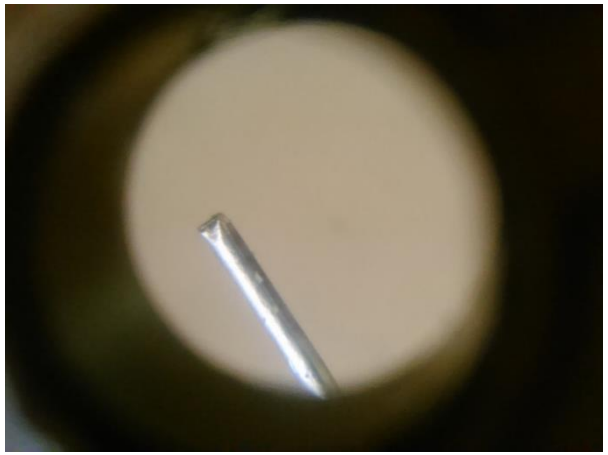


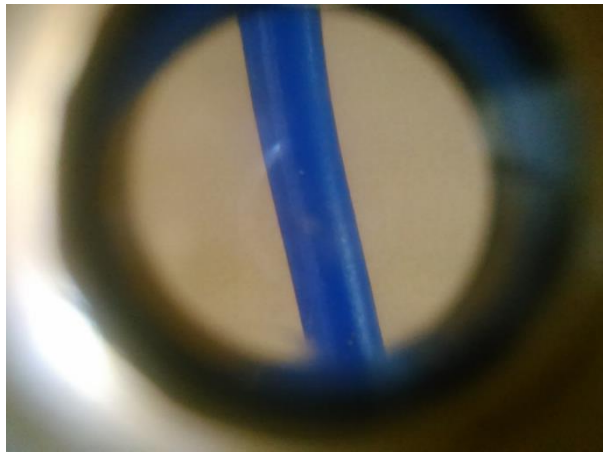
Image 68-73. *Test rig of smartphone microcopy*

Output images from Test Rig : 1st attempt

Electric wire having dia 0.1 and the casing of wire having dia approx. 1mm

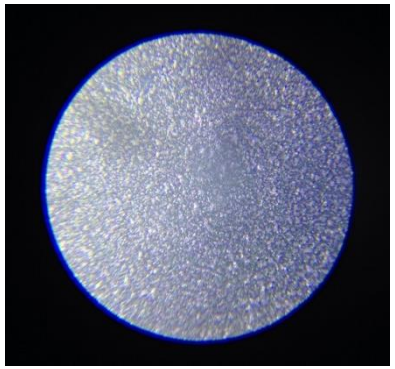


40x by using 12MP camera smartphone

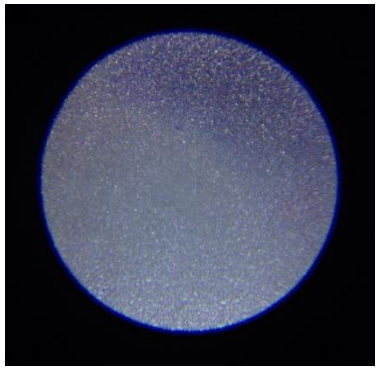


40x by using 12MP camera smartphone

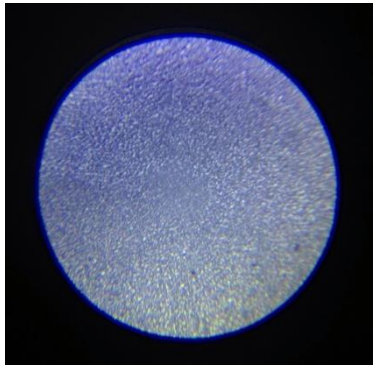
Stained blood slide



40x by using 12MP camera smartphone



40x by using 8 MP camera smartphone



40x by using 2 MP camera smartphone

***Image 74-78. Outputs of** Test rig of smartphone microcopy*

After lots of observations and discussions with pathologist from Hinduja Hospital the insights got from them are as follows,

1. Need to improve quality of image
2. Need to fix objective lens or replace entire set
3. Need to fix a minimum megapixel smartphone for this project (because 2MP camera is giving is not even readable output image.)
4. Need to increase the magnification from 40x to at least 200x.
5. Need to check blood slide with out stain.
6. Red and white blood cells seen but cant be diagnosed.

Output images from Test Rig : 2-17th attempt

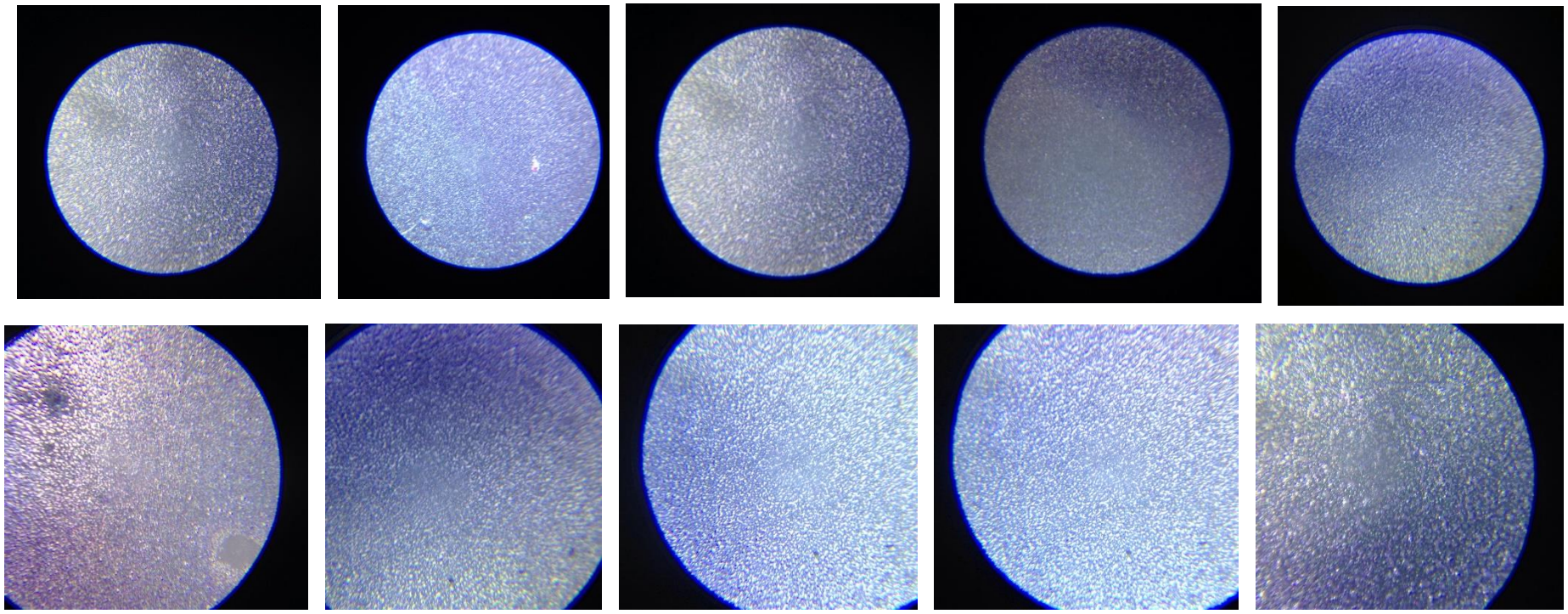
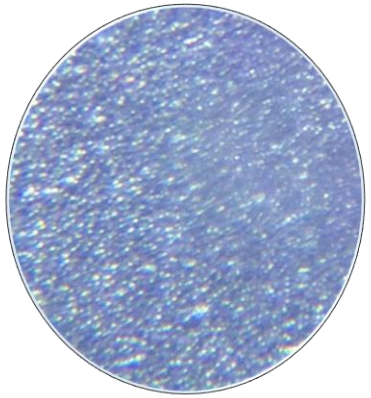


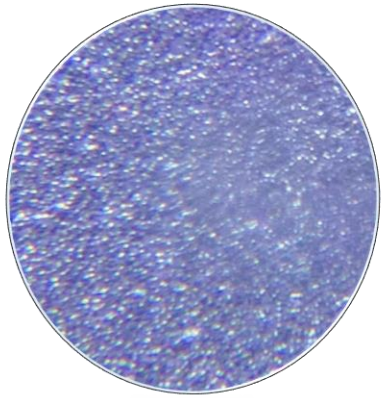
Image 79-88. *Test rig of smartphone outputs*

All the images are taken from 12 megapixel camera and giving maximum 80x magnification value. If we closely observe these images the bluish colored thing is red blood cell and white colored are white blood cells.

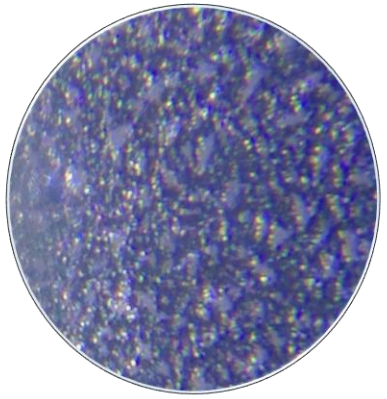
Output images from Test Rig : 18th attempt



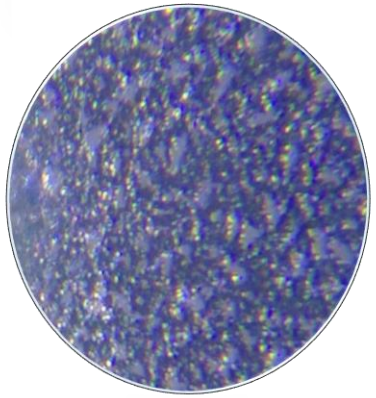
60x by using 12MP camera smartphone



80x by using 12MP camera smartphone



100x by using 12MP camera smartphone



100x by using 2 MP camera smartphone

Image 74-77. *Test rig of smartphone microcopy outputs*

These images ware shown to the pathologist and asked about the visibility of red and white blood cells the insight got from the pathologist from Hinduja Hospital is that red and white blood cells are clearly visible in image 3rd and can be diagnosed. The total height of the lenses setup was 4.8cm which was frozen and started casing work of the equipment . How it will fix on the smartphone ,how it would be universal designed and etc. The concept generation of casing started here after.

Design considerations for medical devices in rural India

1. Accuracy, Reliability and Durability

Accuracy, reliability, and durability are three of the most important design considerations. The specific end user of the product will determine the need accuracy for the product. Reliability and durability are generally much more important to the end consumer compared with accuracy. Due to a multitude of products which don't have reliable warranties or products which have been donated with little or no support, reliability has become a major consideration in the purchase of a product.

2. Size and weight

Space comes at a premium in already scant medical throughout the world. Many patients are generally combined into one single room, which means that products should be as small and light as possible which can lead to an increased portability.

3. Materials

If medical devices are intended for production on a large scale, care must be taken to ensure that these materials will be available for distribution within the country.

4. Power requirements

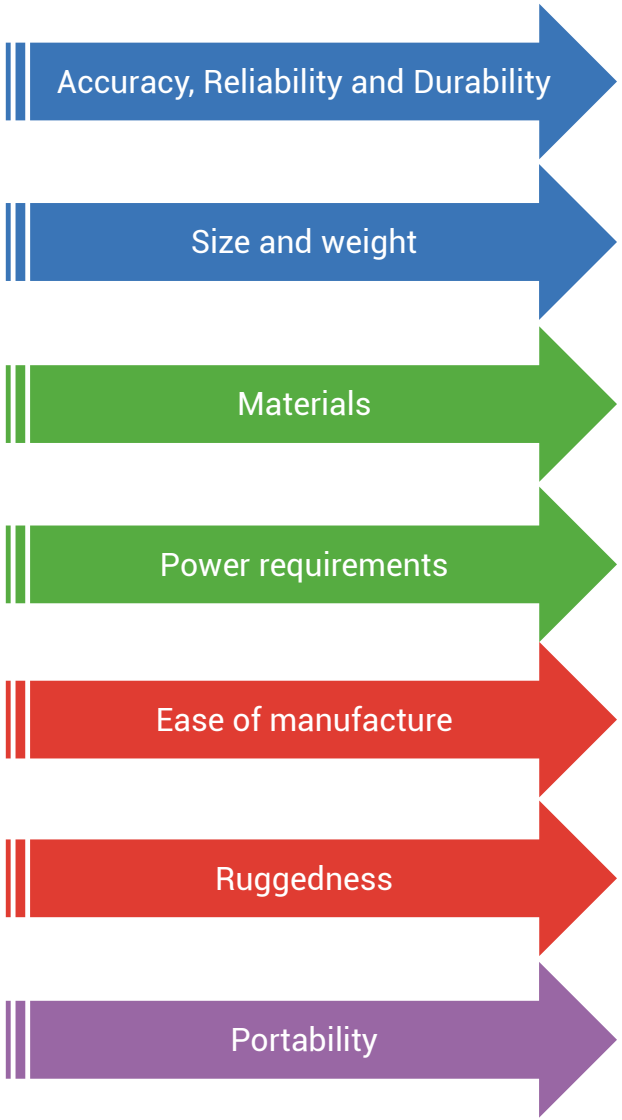
Any devices which is electrical in nature, must take into account the power concerns throughout the country. Medical devices which operate on battery power are especially important in countries like India, which don't have assured power supply for an extended period. Not only should batteries be used as a means of electrically isolating the high voltage wall outlet, but also they are required to ensure that medical devices will continue to operated since in India, power can be sporadic at best.

5. Ease of manufacture

As many of the devices which will be designed will be ideally sold and manufactured in the same country, ease of manufacture should be taken into concern. The easier it is to manufacture a product the better.

6. Language issues

Language issues should be addressed for many countries within the developing world as multilingual countries are far more common as compared with developed countries. Specifically in India 29 languages



are spoken by more than a million native speakers, 122 by more than 10,000.

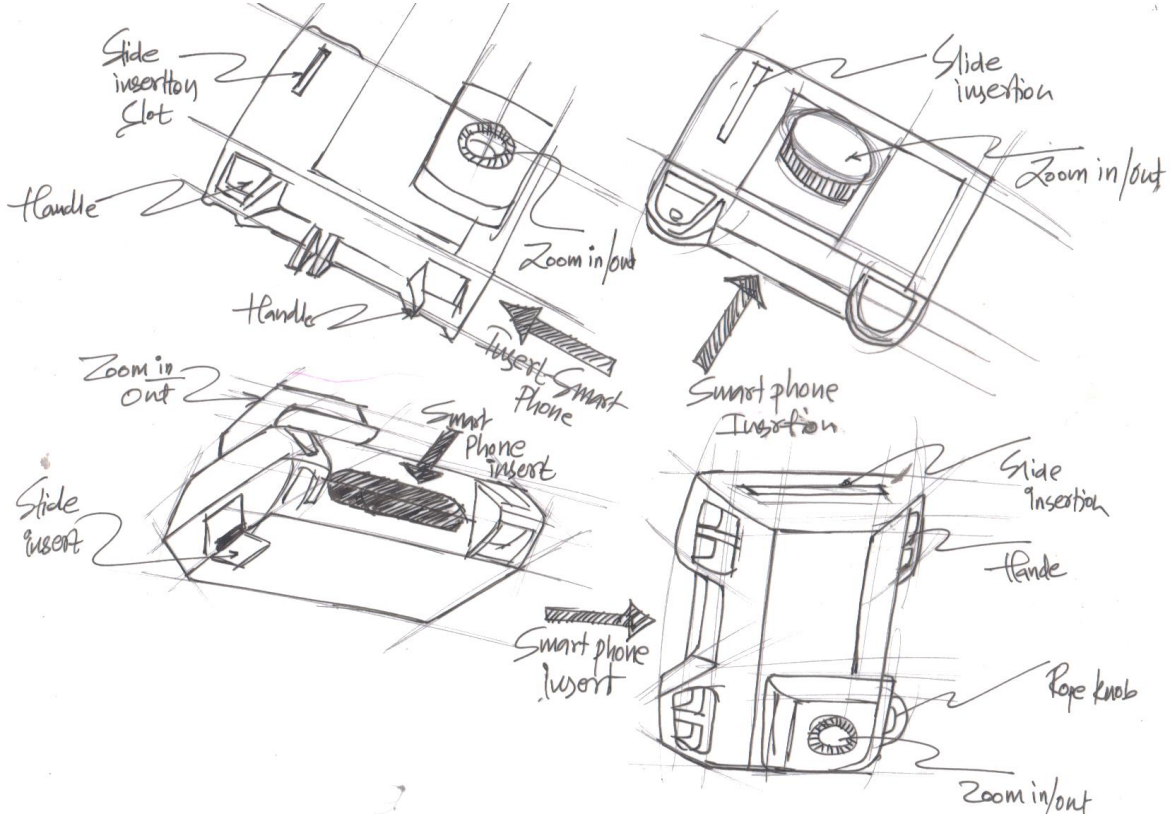
7. Ruggedness

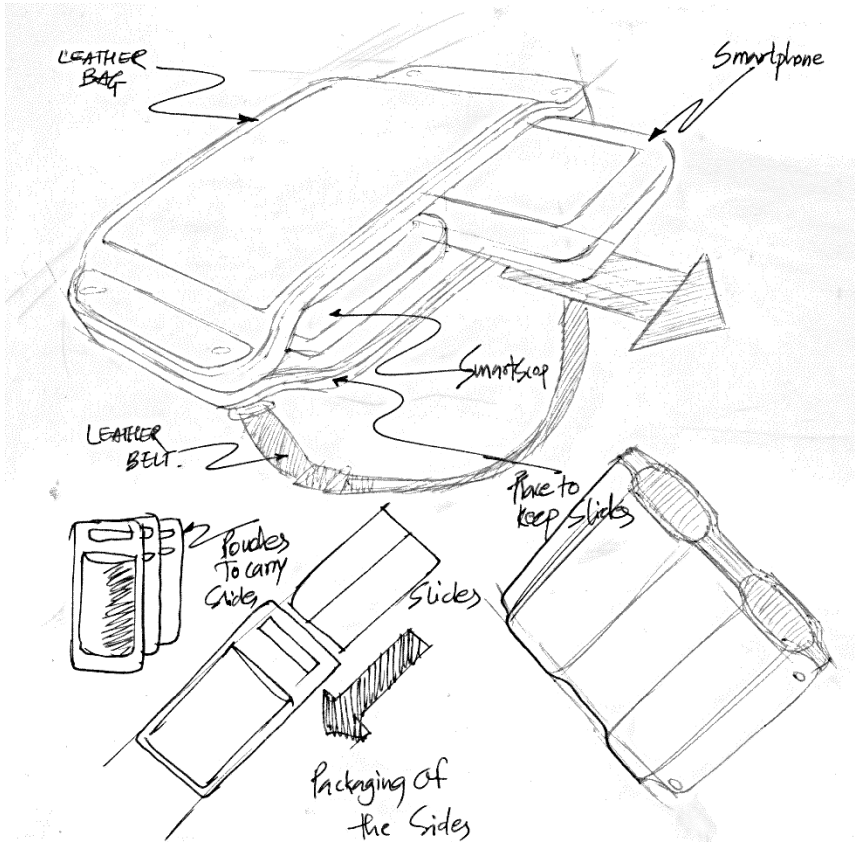
The device has to operate in rural India, a landscape which varies from arid deserts to cold mountains to swampy marshlands with humans living in all these conditions. Thus, the device has to be able to operate perfectly under all these conditions at an acceptable performance level.

8. Standards compliance

There is an age-old practice of skimping on quality when it comes to production in India. Since these products are for the poor people, there is a very good chance of foul-play with the same. We should look closely at the best standards available and ensure while designing.

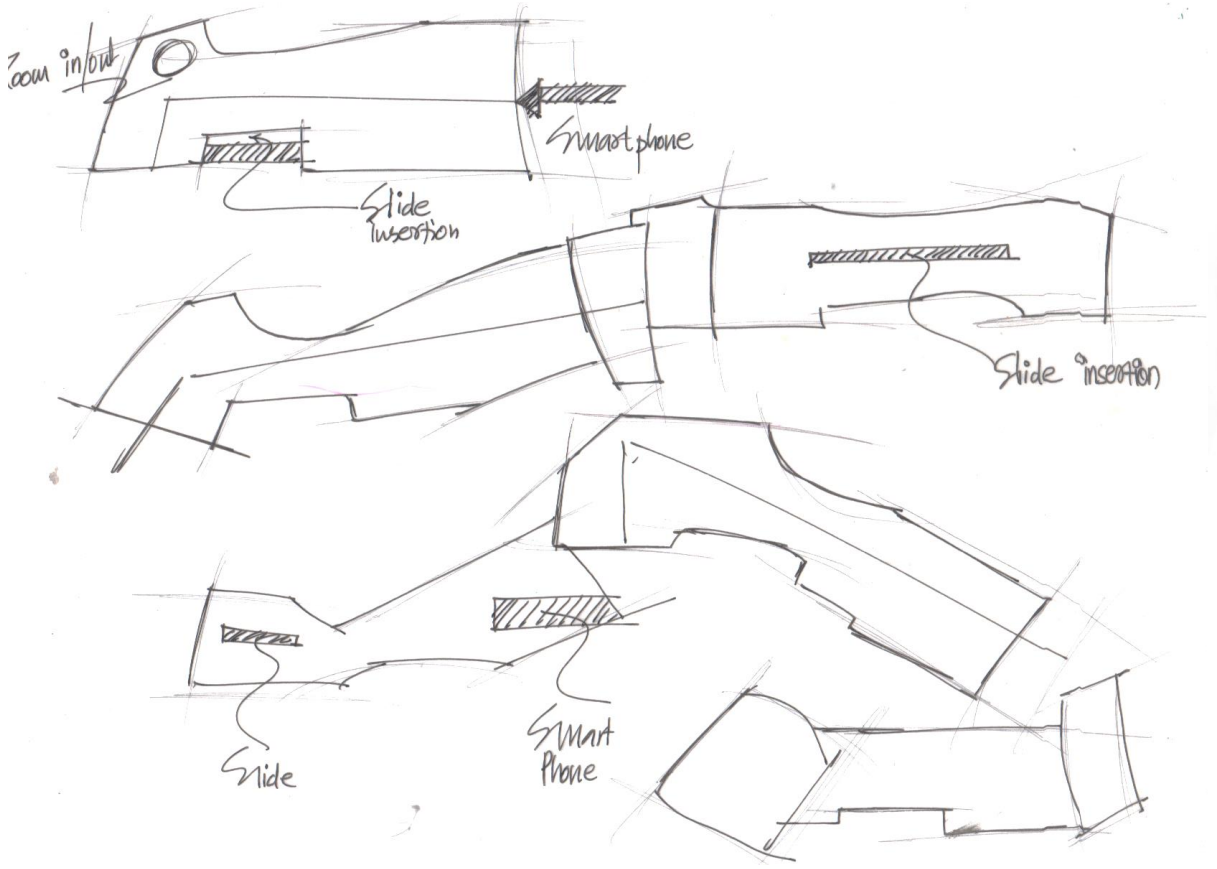
Concept I

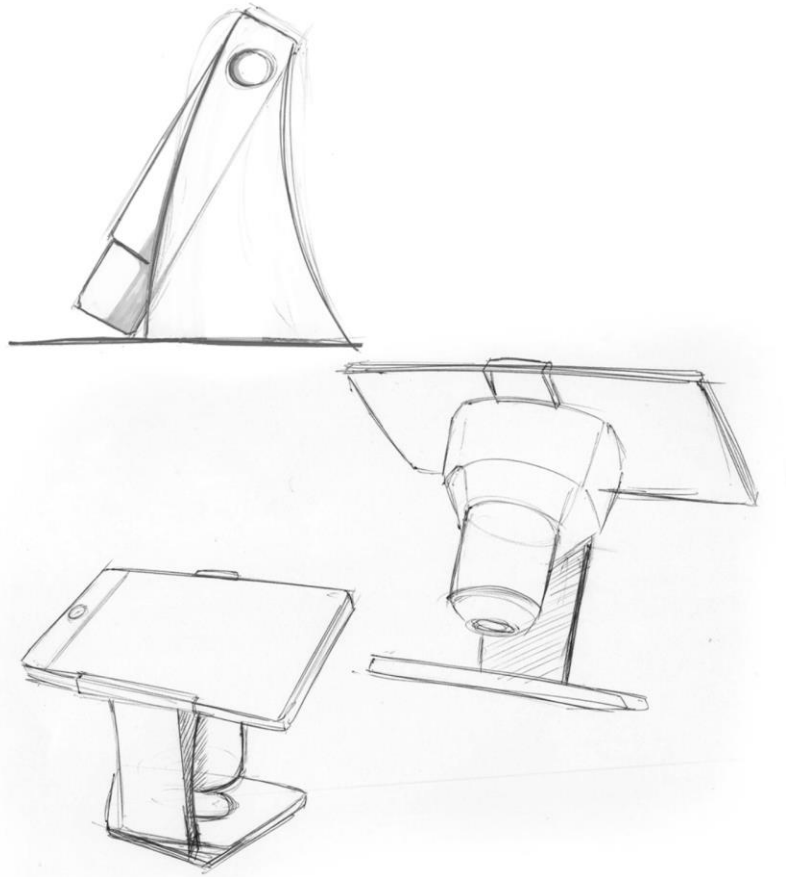




Concept I is a simple concept where smartphone is inserted in a add-on device in which the lenses are present. We can zoom in and zoom out the image by fixing the objective lens distance. This devise will give us magnification from 40x to 100x. .The concept drawing on the right shows the casing of the product where the place for staining the slides is given for stain A and Stain B. the casing also have a place to keep the slides and separate compartment for used slides.

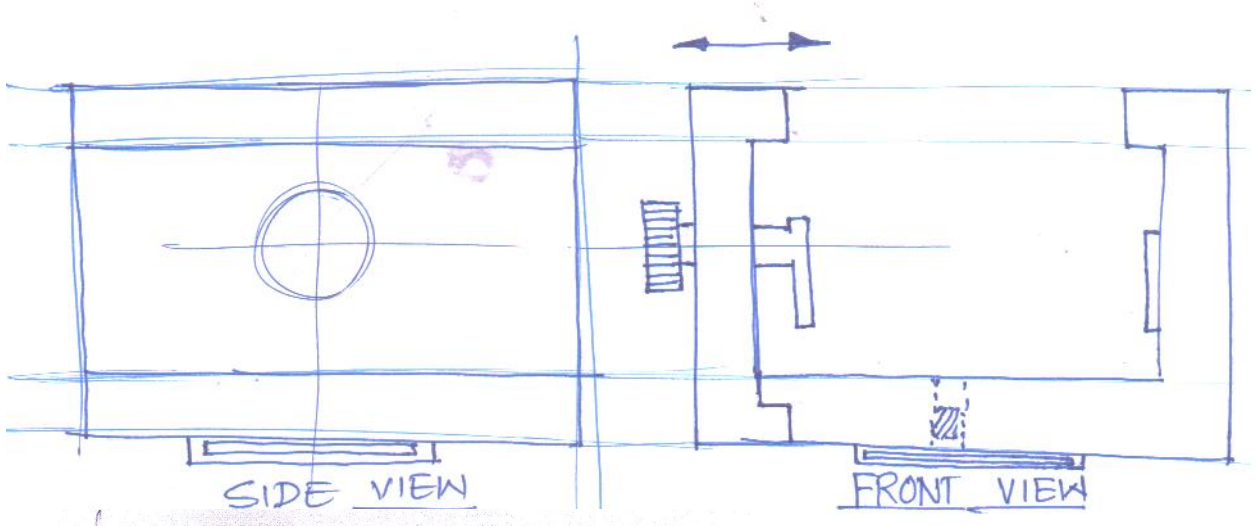
Concept II

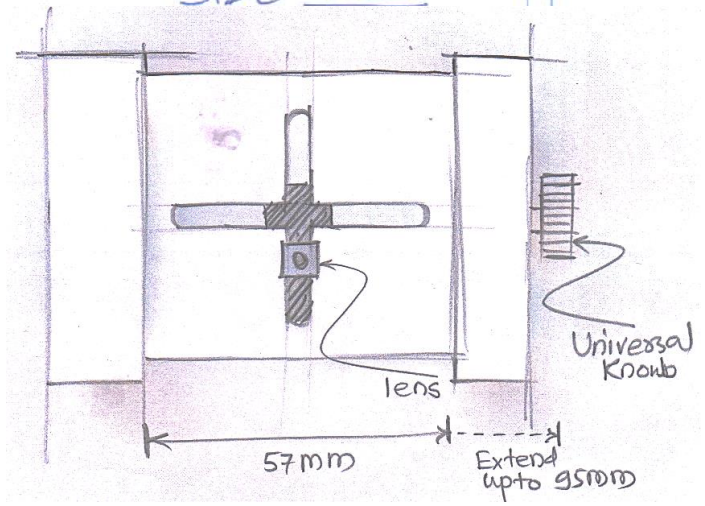


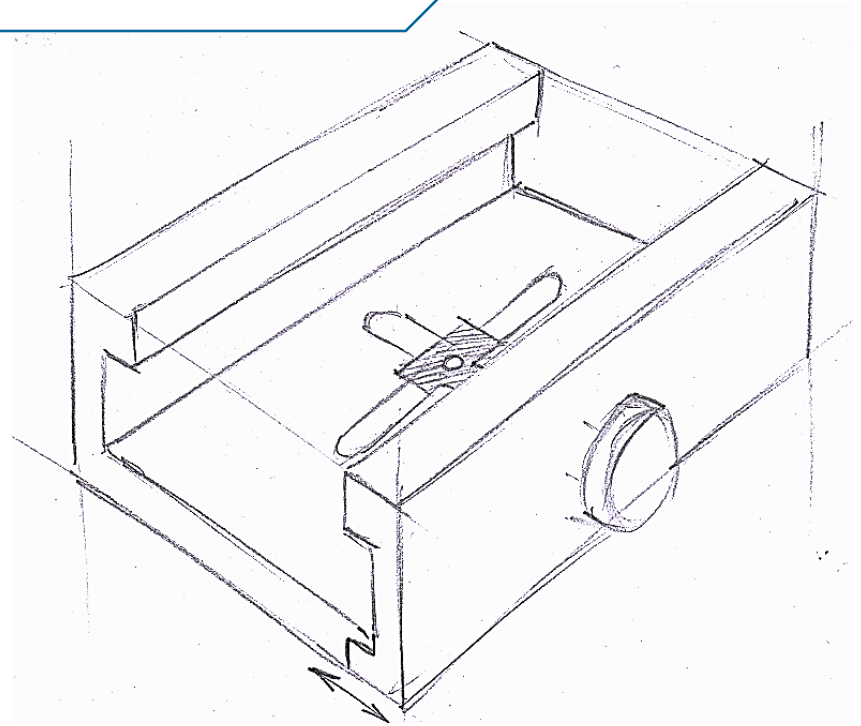


In Concept II the smartphone itself will cover by the device that means smartphone will get inserted in that device which is already have the provision of microscope. Or the modern version of this concept which is shown at the right side placing the smartphone on the stand where that stand itself plays a role of the microscope.

Concept III

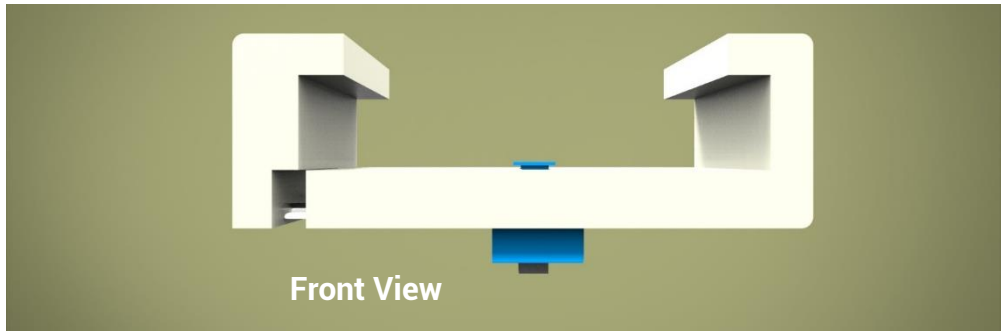


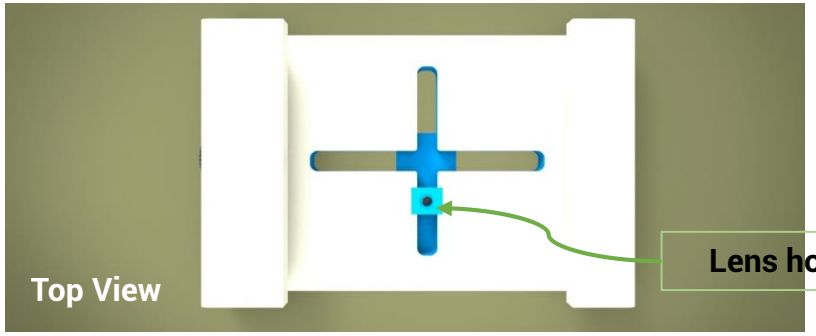


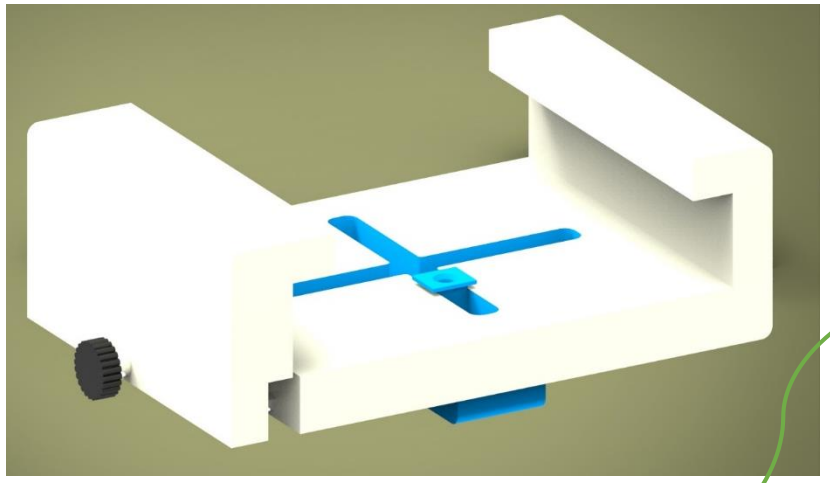


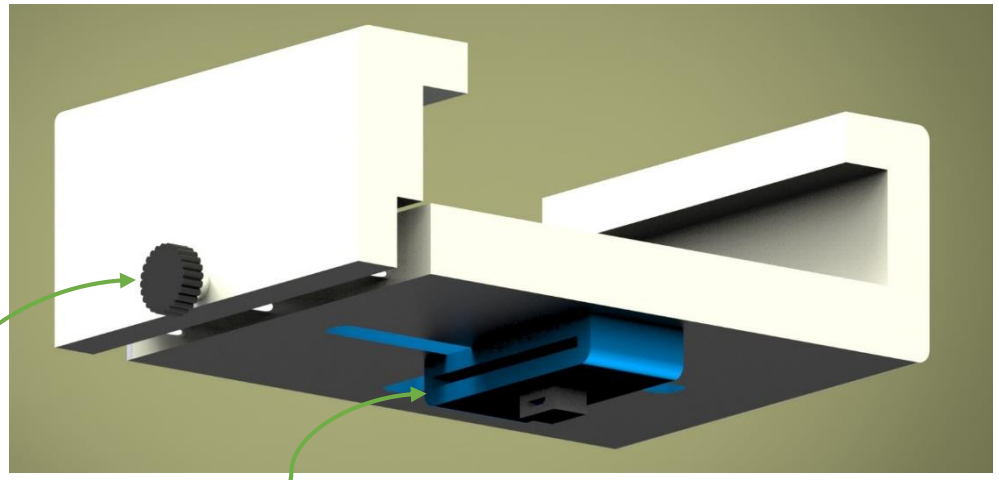
This concept is designed bye keeping in mind the varying sizes of the smartphone and the location of the mobile camera module. During market study of smartphone it is observed that the camera location is in 3 different places for different smartphones. It depends on the company. The Samsung prefers to keep camera at corner and Sony prefers to keep camera at the center and etc.. In order to tackle this problem this design is universal as the lens can be adjusted in x and y direction after fixing the smartphone in the device.

Concept III CAD model









Clamping knob

Slide insertion

New Innovative concept : Use of glass bead in blood diagnostic.

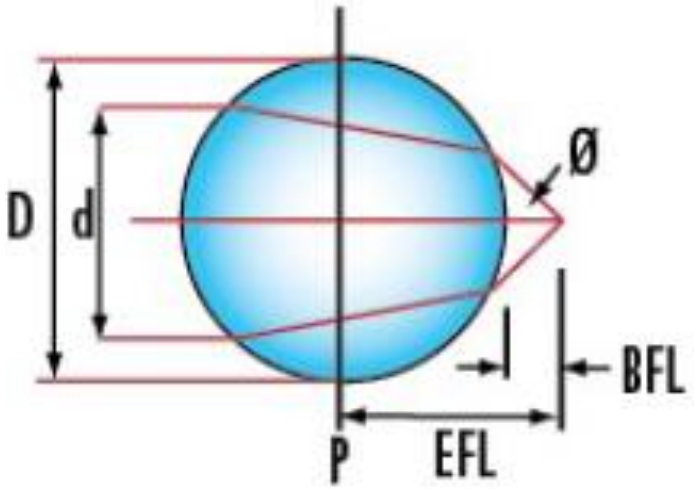
Image 78. *Glass bead*

While doing experimental study on lens ,accidently came to know that A sphere or ball performs surprisingly well as a lens that is the glass beads can be used as a lens in this project. Glass beads are also known as ball lens.

The theoretical and practical study started towards getting 100x magnification value. While understanding more about ball lens came to know that these are already using in healthcare sector in endoscopy.

Ball lenses are great optical components for improving signal coupling between fibers, emitters, and detectors. They are also used in endoscopy, bar code scanning, ball preforms for aspheric lenses, and sensor applications. Ball lenses are manufactured from a single substrate of glass and can focus or collimate light, depending upon the geometry of the input source. Half ball lenses are also common and can be interchanged with full ball lenses if the physical constraints of an application require a more compact design.

Understanding Ball lens/Glass bead



There are five key parameters needed to understand and use ball lenses (Figure 1): Diameter of Input Source (d), Diameter of Ball Lens (D), Effective Focal Length of Ball Lens (EFL), Back Focal Length of Ball Lens (BFL) and Index of Refraction of Ball Lens (n).

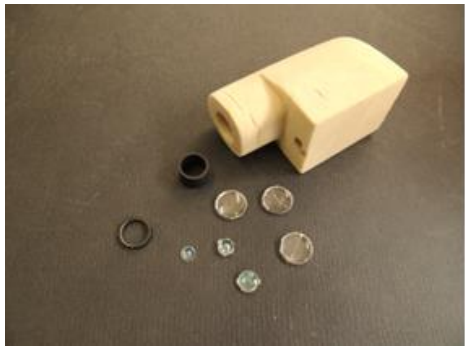
Why Ball lens ?

Image 79 *Glass bead manufacturing unit,Mumbai*

A ball lens is spherically shaped, generally possesses a constant refractive index, and is made from commonly available glasses or other transparent optical substrates. The main advantage of ball lens is the reduced size, availability, and cost benefits.

To know more about ball lens / glass bead ,visited Hindustan Glass beads, Vinochem Industrail Estate, Goddeo Road, Lazarus Park, Bhayandar East, Mira Bhayandar, Mumbai. A glass beads manufacturing firm in north Bombay. From there almost all size right from 1mm to 3.5mm of size glass beads collected and started experimental study with them.

Experimental study with Ball lens and it's result



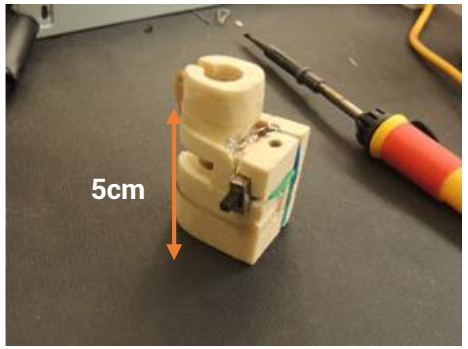
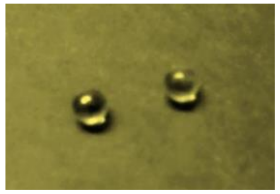
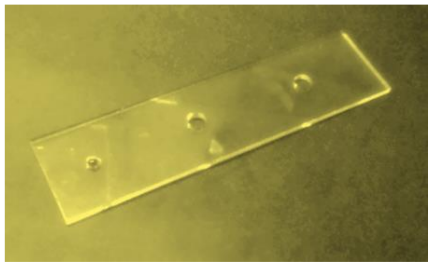
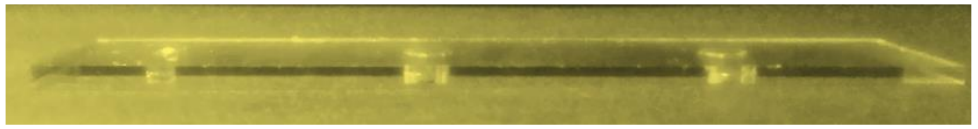


***Image 80-81** Test rig microscope*



Dia= 2.9mm





Thickness of this acrylic sheet is 1mm

***Image 82-84** Glass bead's acrylic holder*

While duing experimental study with ball lens the following output came.

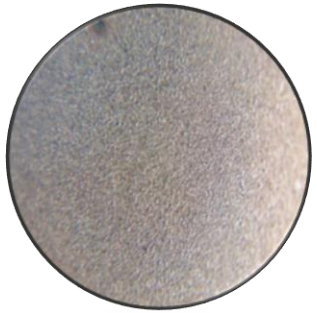


***Image 85**. Stained blood slide with 200x magnified blood cells.*

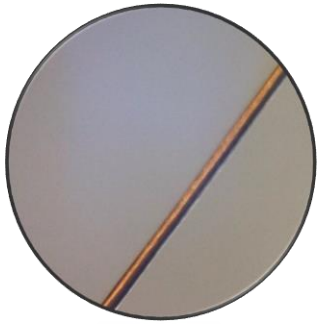


***Image 85**., Human hair with 200x Magnification.*

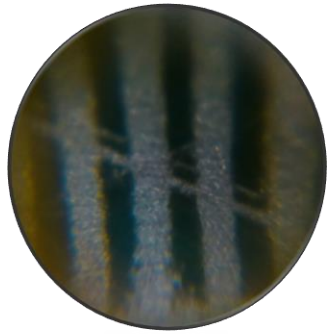
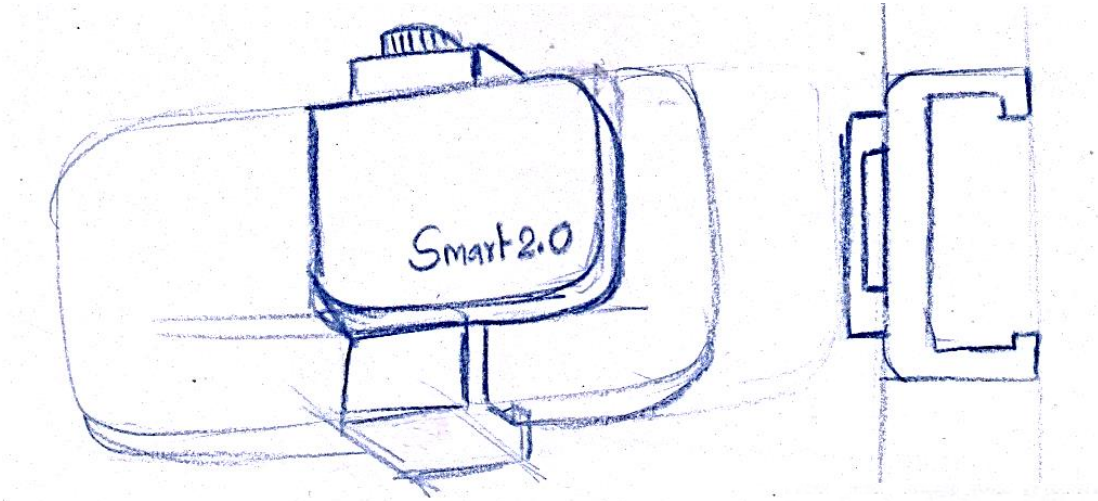


***Image 86**., Steel rule.*

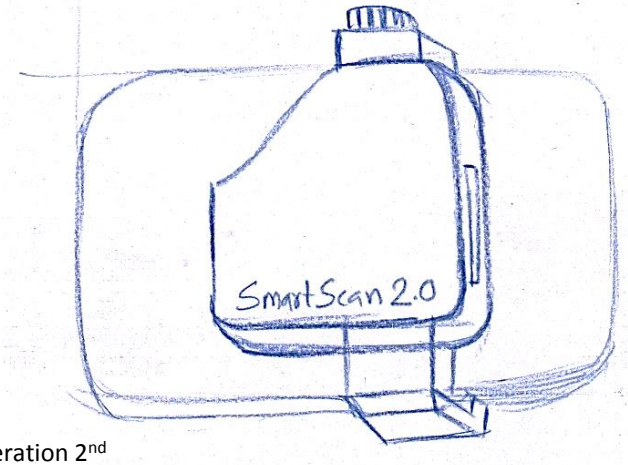
So, In this way the base requirement of max.200 x magnification of the stained blood cells is achieved by using this simple glass beads having diameter 2.9mm. Due to this the height of the add-on device is reduced from 5cm to almost 1cm.

Final Concept



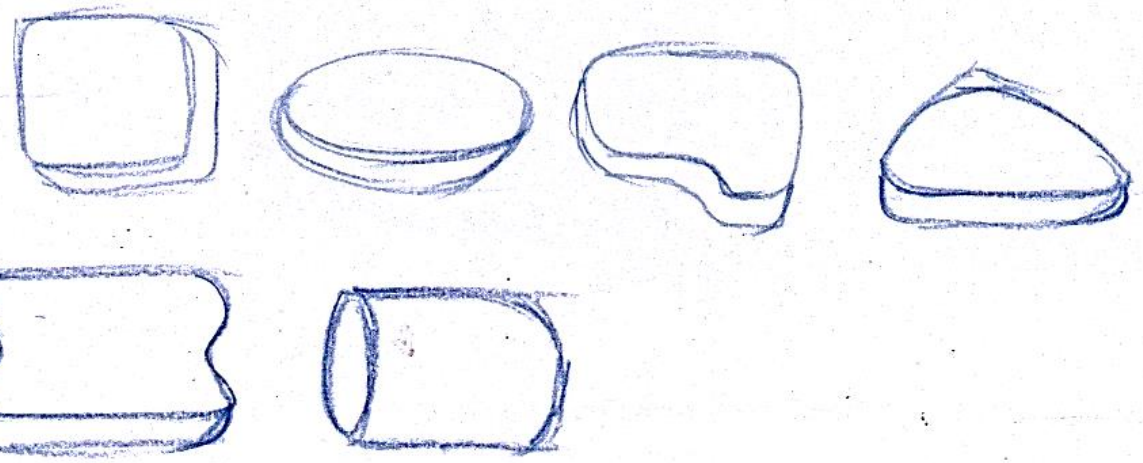
Iteration 1st

Very thin devise made up of ABS by injection molding process. The devise have a facility to change the lens too. The ball lenses is used here which is so cheap so the automatically the prize of devise came down. The estimated cost of the device is Rs.50 only. We can use this smartphone microscope for other diagnostics also due to interchangeability of lens.



Iteration 2nd

Form Exploration



Mood Board

Colors

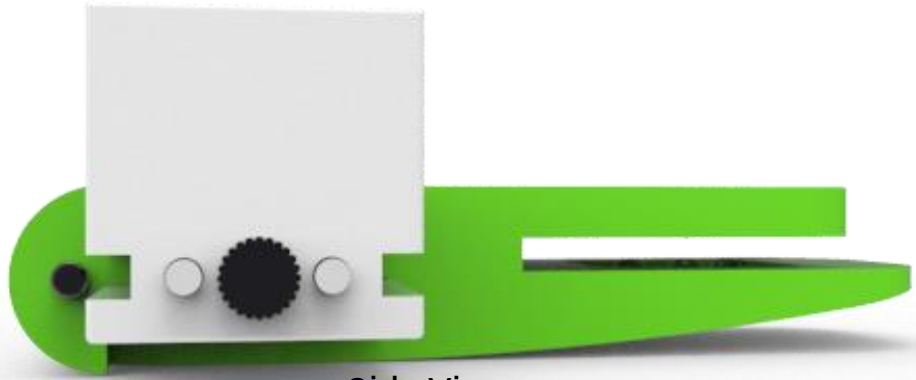
Textures

Shapes

This mood board is focused on providing the sense of safety and gentleness with undertones of reliability. Feminine rounded curves are the strong design element here along with simplicity and smoothness achieve soothing shapes that rests in the hand.

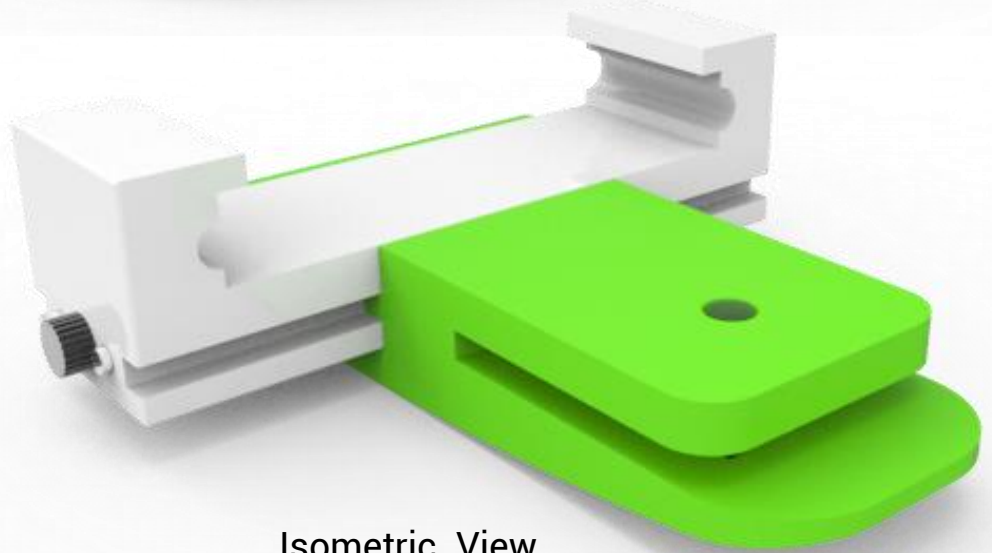
Concept CAD model

Front View



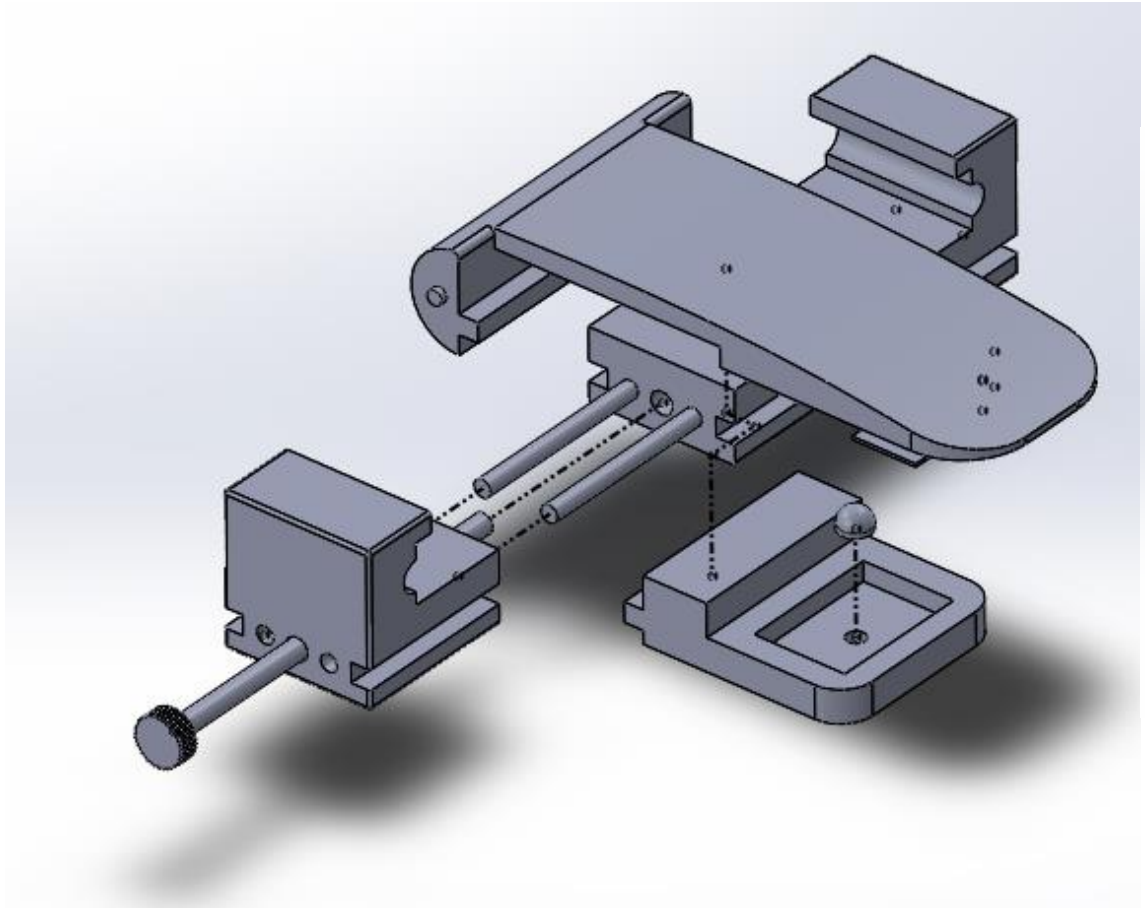
Side View

Back side View



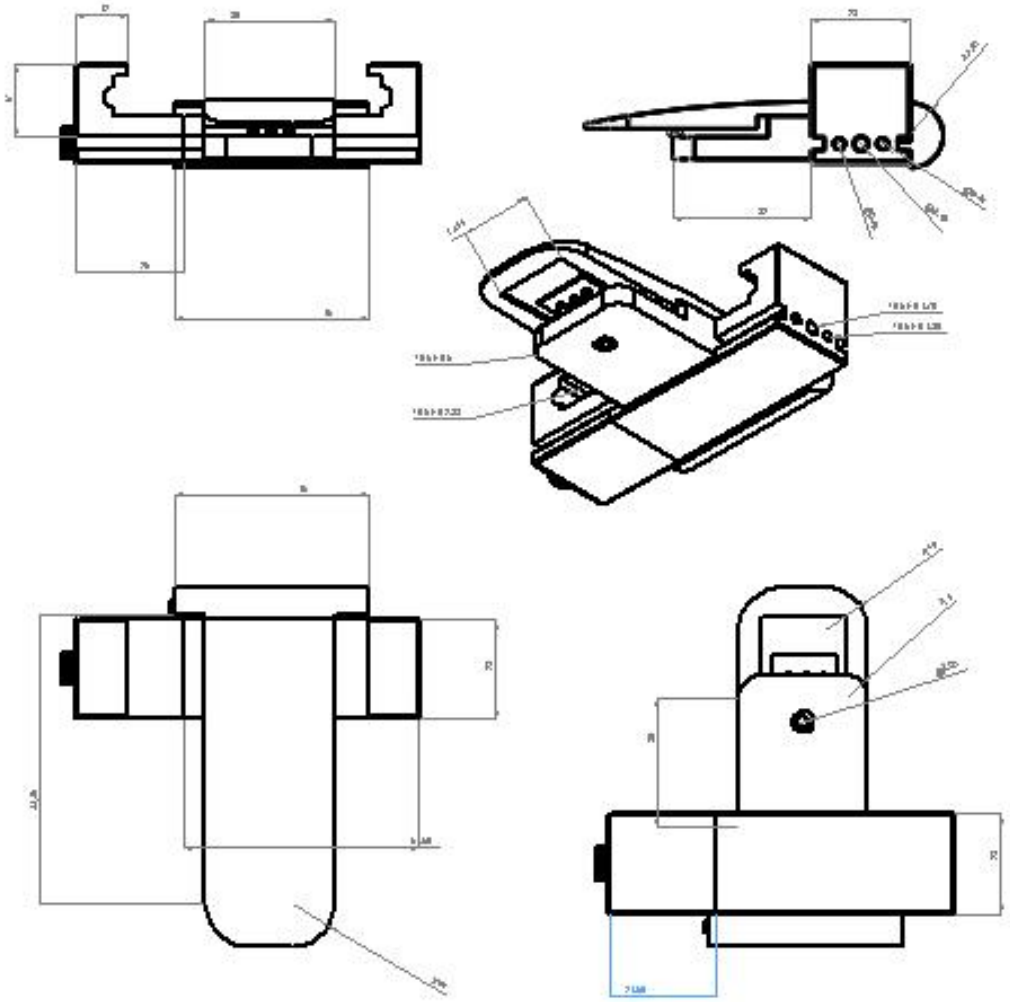
Isometric View

Exploded view and BOM

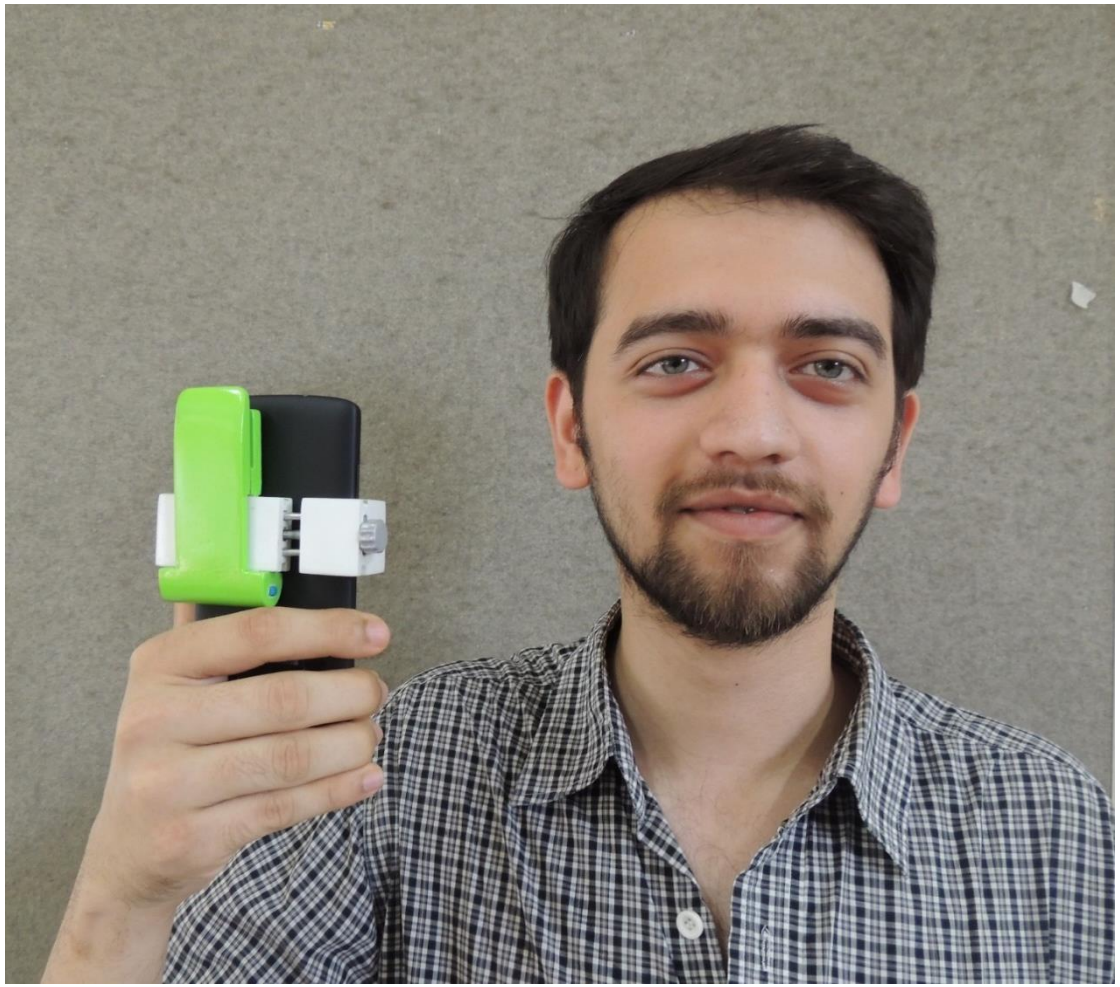


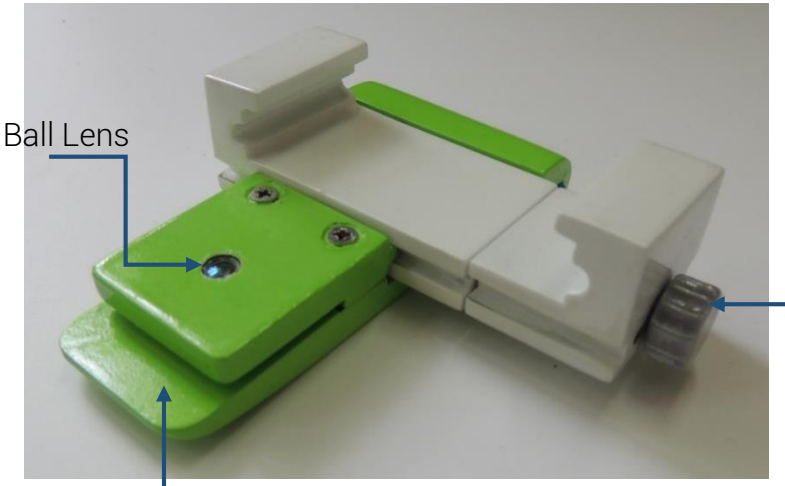
BOM Table				
ITEM NO.	PART NUMBER	Material	Manufacturing Process	QTY.
1	Main Body	Acrylonitrile butadiene styrene (ABS)	Injection Molding	1
2	Base Part 2	Acrylonitrile butadiene styrene (ABS)	Injection molding	2
3	Bolt	Steel	Rolling	1
4	Slider	Steel	Wire Drawing	1
5	Main Body Part 2	Acrylonitrile butadiene styrene (ABS)	Injection Molding	1
6	Lens	Glass Bead	Droplet technology	1
7	Base Body Part 1	Acrylonitrile butadiene styrene (ABS)	Injuction Molding	1

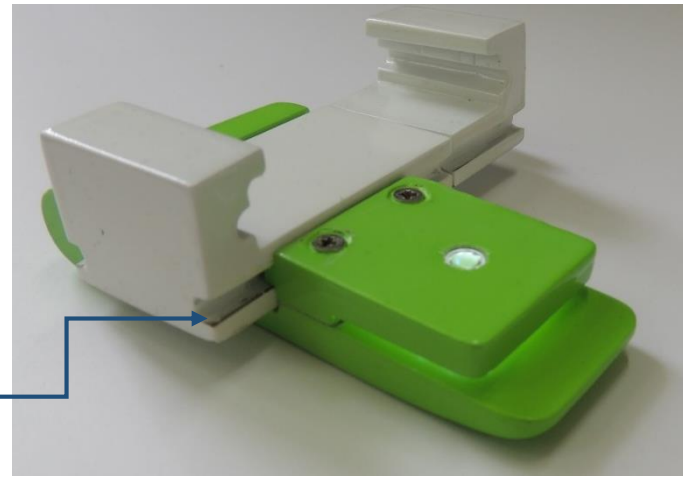
Engineering Detailing



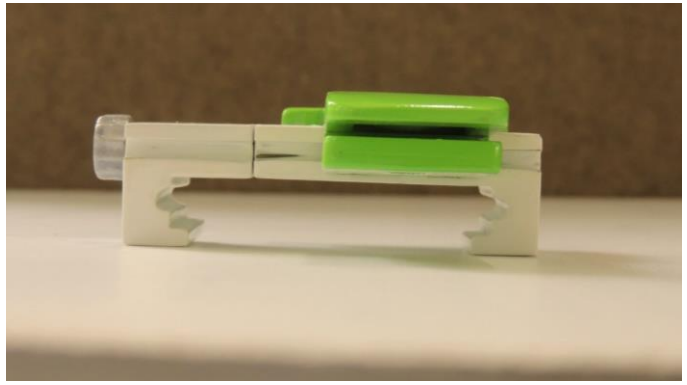
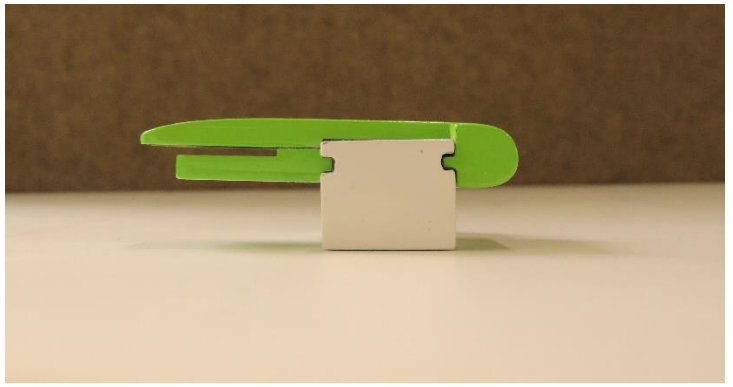
Actual Product -1:1 working model

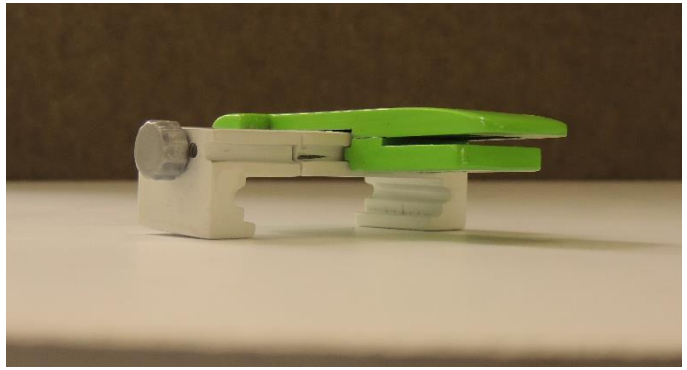
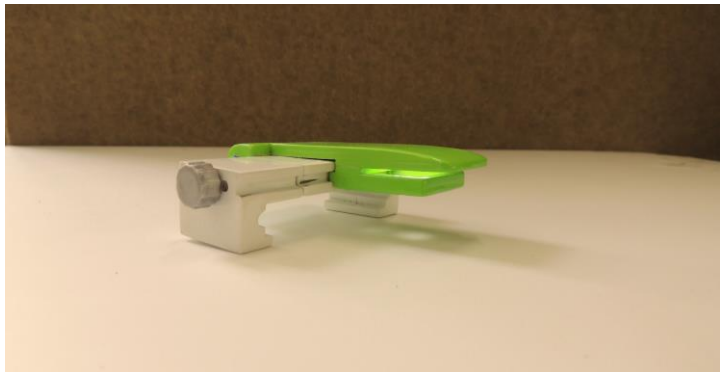






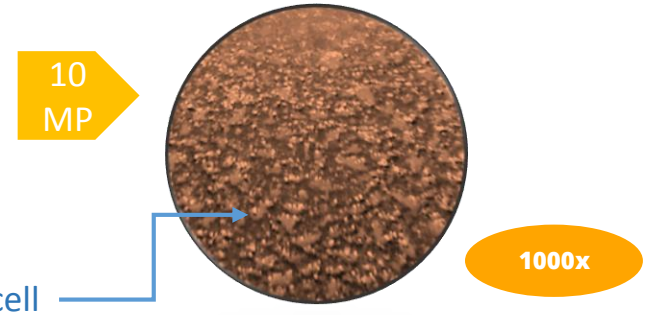
Actual Product -1:1 working model


User Validation

- Bapat's Pathalogy Lab,Powai
- Zoctr Family Clinic,Powai
- Health spring Community Medical center,Powai
- Sangivani Pathalogy Lab,Powai
- Quaklife Pathalogy Lab,Bhandup



Logo Design

Last one selected as a brand logo for this project as the logo. The dark blue on white background gives a sober and simple look.

Conclusion

The SmartScope and the overall system that empowers it is very much realizable in the present day. The system rides on the current advancement in technology from image processing softwares and high speed wireless network to manufacturing techniques and mobile digital devices. However, the real human advantages of the design are:

- Allows unskilled people to use the kit
- Much faster process due to digitization and semi automatic diagnosis process
- Very accurate database for everyone to use

If implemented, the system has the potential to revolutionize the world of blood diagnosis, specially in developing countries like India.

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11. "The World in 2015: ICT facts and figures." 2014. *ITU*. Accessed Jan22. http://www.itu.int/en/itu-d/statistics/Pages/default.aspx.
12. Tseng ,Derek, Onur Mudanyali ,Cetin Oztoprak, Sehan O.2010 "Smartphone Based Computational Microscopy Using Multi-frame contact Imaging in a fiber optic array." 13(20. Oct),2014-4030.