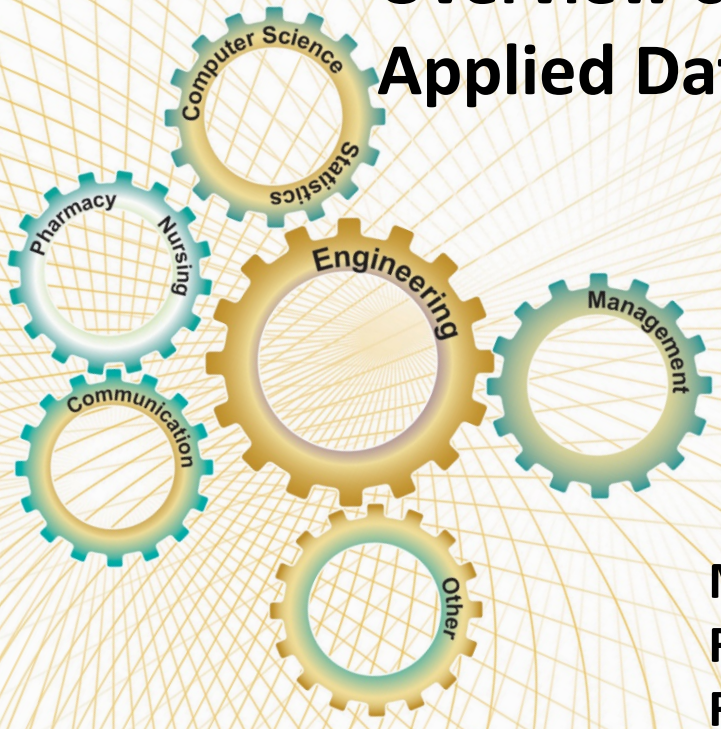
Mobile-based Hgb Level Detection and an Overview of mHealth, Informatics and Applied Data Science



Md Munirul Haque
Research Scientist
Regenstrief Center for Healthcare Engineering
Purdue University

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BACKGROUND

- Smartphone-based Hemoglobin Analyzer (sHEA) (Kenya)
- Diagnosis-Based Demand sensing and Digital tracking (Uganda)
- mCARE: Mobile based autism care (Bangladesh)
- Secondary Data Analysis on Mozambique OpenMRS Dataset (Mozambique)
- REMEDI (USA)

SMARTPHONE-BASED HEMOGLOBIN ANALYZER (SHEA)

- Affordable, portable, and user-friendly solution to the global anemic community
- Anemia affects 24.8% of the global population (1.62 billion people)
- In Africa, anemia affects two thirds of preschool-age children and a half of women
- When anemia is not detected and managed in a timely manner, it can result in major health consequences
  - Fatigue
  - Heart failure
  - Pregnancy disorders
  - Poor physical/cognitive conditions
- Early and accurate diagnosis of anemia can reduce a need for complicated treatments

OBJECTIVE

Develop a mobile imaging technology for non-invasive assessment of anemia

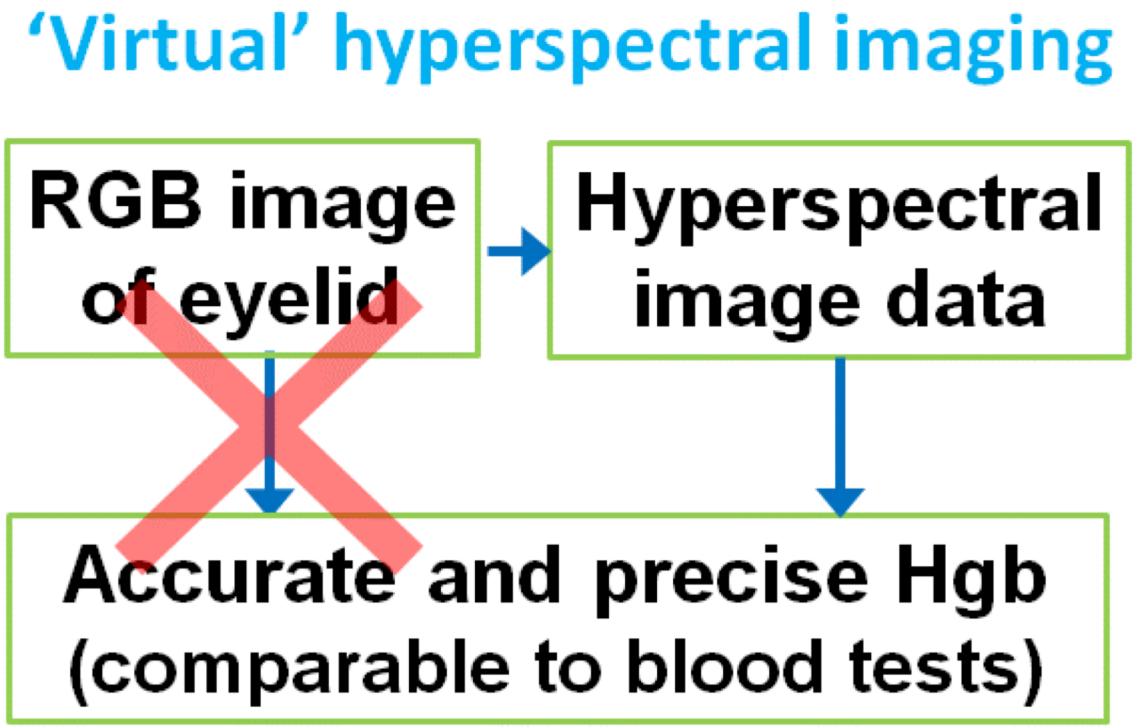
Aims:

1. Build a dual telecentric imaging system to provide a platform for estimation of hyperspectral information from RGB image data.
2. Conduct clinical studies using the dual telecentric imaging system, to acquire data set to develop algorithm for reconstruction of hyperspectral data from RGB.
3. Development of the mobile app and usability testing
4. Measurement on the accuracy of the app on real life subjects

COMPARISON TABLE

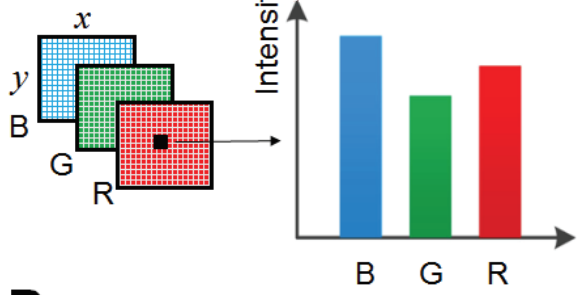
Technology	Bloodless (noninvasive)	Smartphone embedded (cost-effectiveness)	Sensing site	Accuracy and precision (comparable to blood tests)
i-STAT	No	No (stand-alone)	NA	Yes
HemoCue	No	No (stand-alone)	NA	Yes
Haemospect	No	No (stand-alone)	Finger	Yes
OrSense	Yes	No (stand-alone)	Finger	Yes
TouchHb	Yes	No (attachment required)	Finger	No
HemoGlobe	Yes	No (attachment required)	Finger	No
HemaApp	Yes	No (attachment required)	Finger	No
Pallor exam	Yes	Yes	Eyelid	No
Eyenaemia	Yes	Yes	Eyelid	No
sHEA	Yes	Yes	Eyelid	Possibly Yes

CHALLENGE


'Virtual' hyperspectral imaging
RGB image of eyelid
Hyperspectral image data
Accurate and precise Hgb (comparable to blood tests)

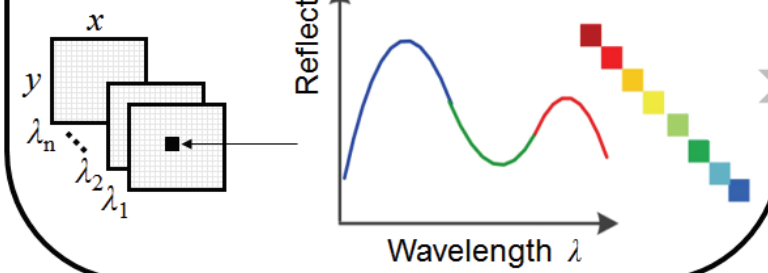
SHEA OVERVIEW

RGB image data

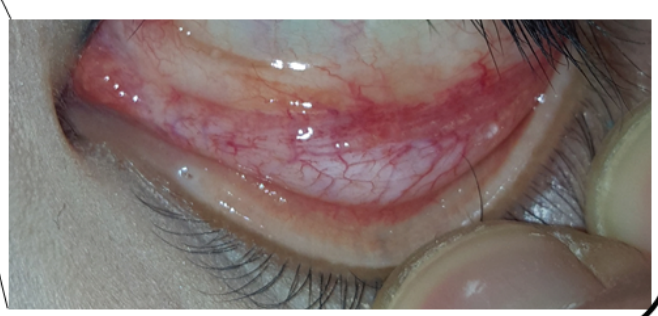


B. Mathematical hyperspectral reconstruction

Hyperspectral image data



A. Inner eyelid imaging with a smartphone



C. Mobile application for the proposed Hgb quantification, comparable to lab blood tests

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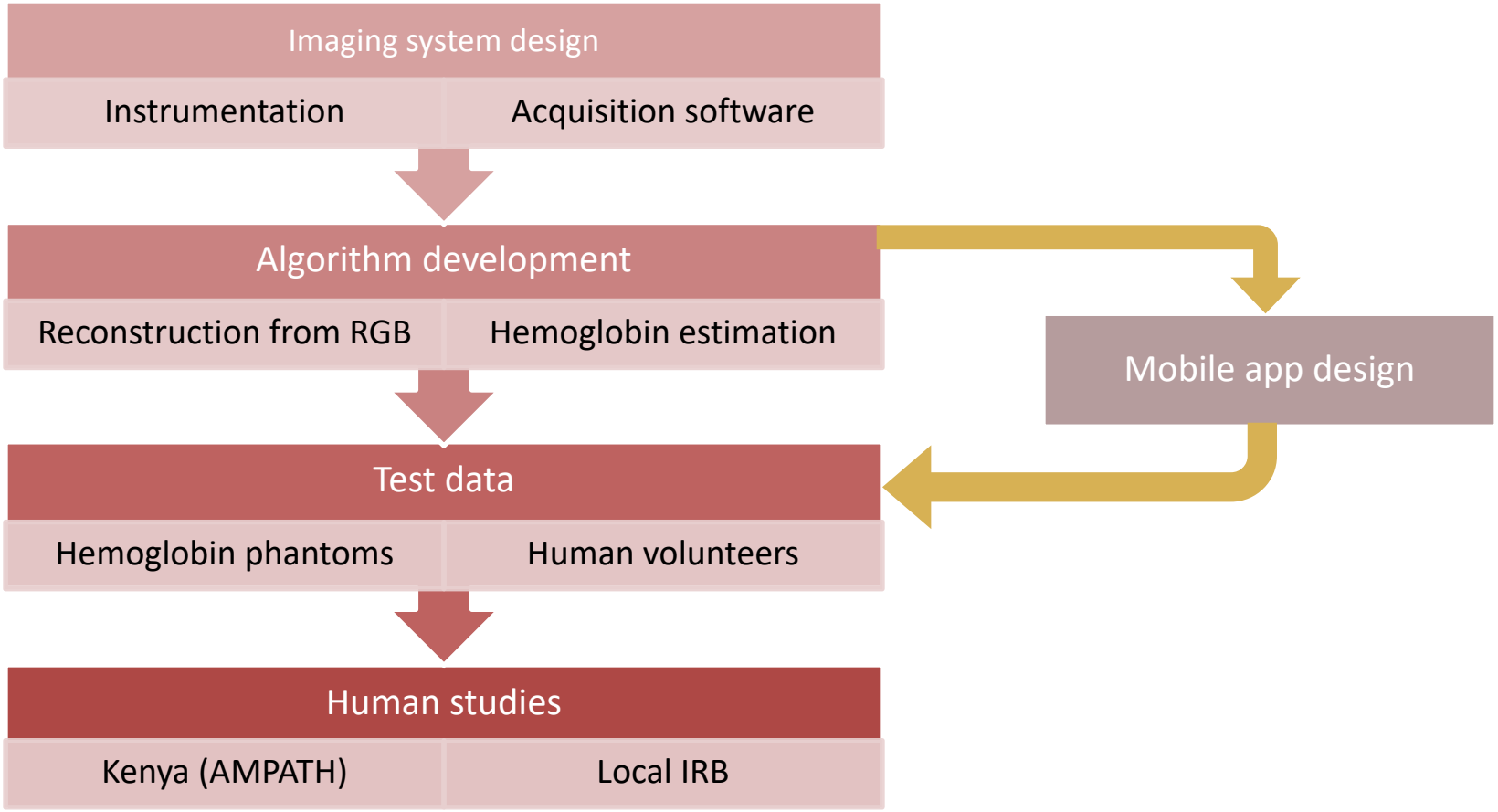
PROJECT OVERVIEW



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TWO-STEP ALGORITHM

Reconstruction from RGB

1. Acquire hyperspectral and RGB training data set, with known Hemoglobin values
2. Develop conversion matrix from training data set
3. Convert RGB image data to hyperspectral information

Hemoglobin estimation

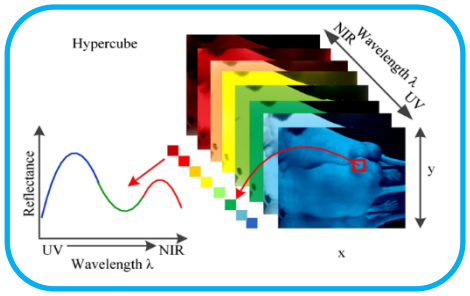
1. From training data set, determine ratio of long to short wavelength in hyperspectral data
2. Build prediction model for Hemoglobin concentration from wavelength ratio
3. Apply prediction model to hyperspectral data to estimate Hemoglobin value

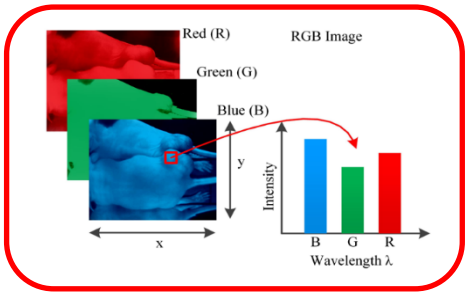
HYPERSPECTRAL IMAGE RECONSTRUCTION

For a simple approach to instrumentation development, hyperspectral information can be reconstructed from RGB data.

This reconstruction algorithm consists of a conversion matrix ***T*** created from a training set such that

$$\hat{R}_{m\times N} = X_{m\times 3} T_{3\times N}$$

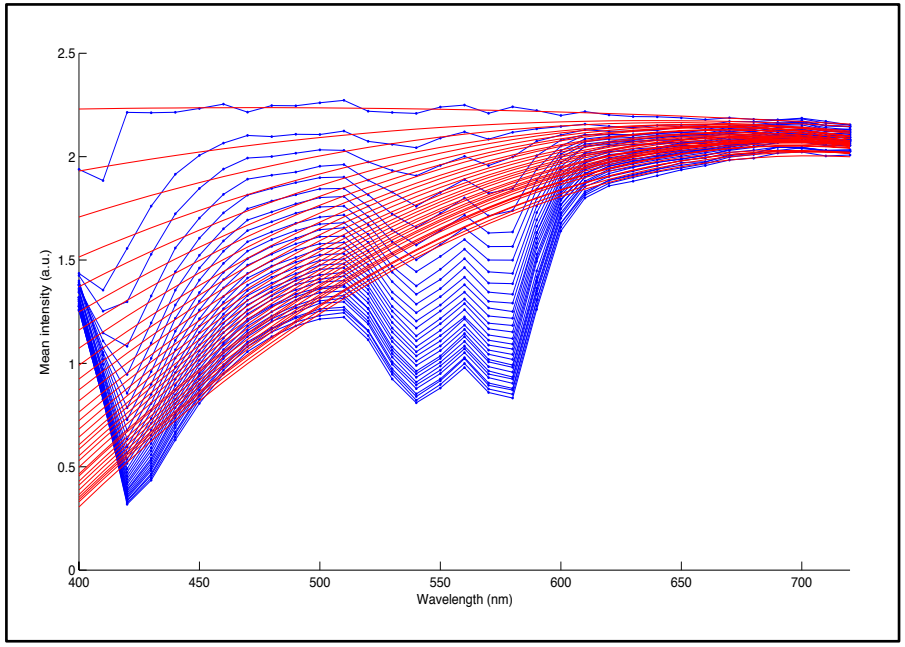




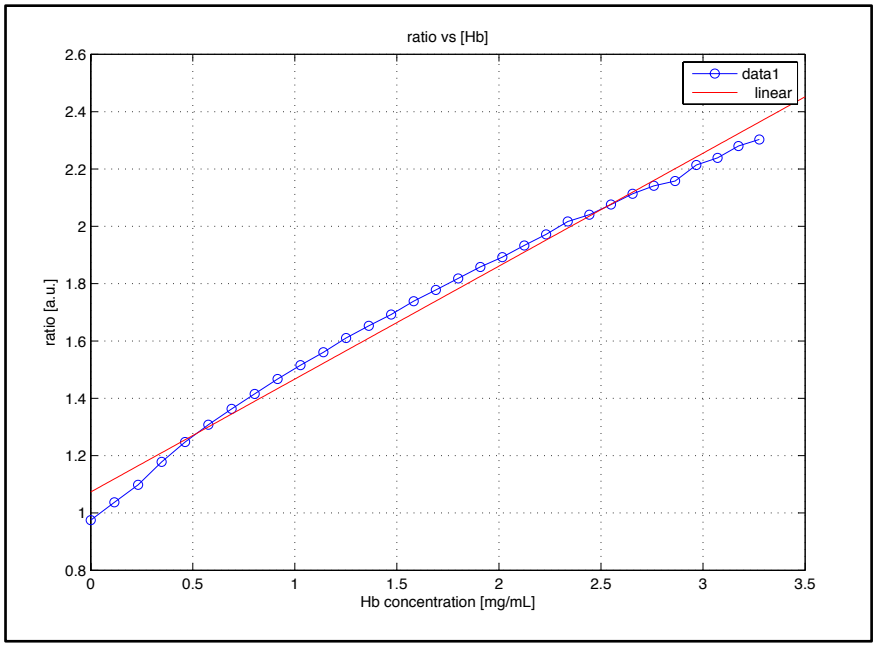
T is obtained via least squares method to minimize differences between original and reconstructed spectra.

HEMOGLOBIN ESTIMATION ALGORITHM

1) Polynomial fitting to Hemoglobin spectra



2) Ratio of long and short wavelengths VS hemoglobin concentration



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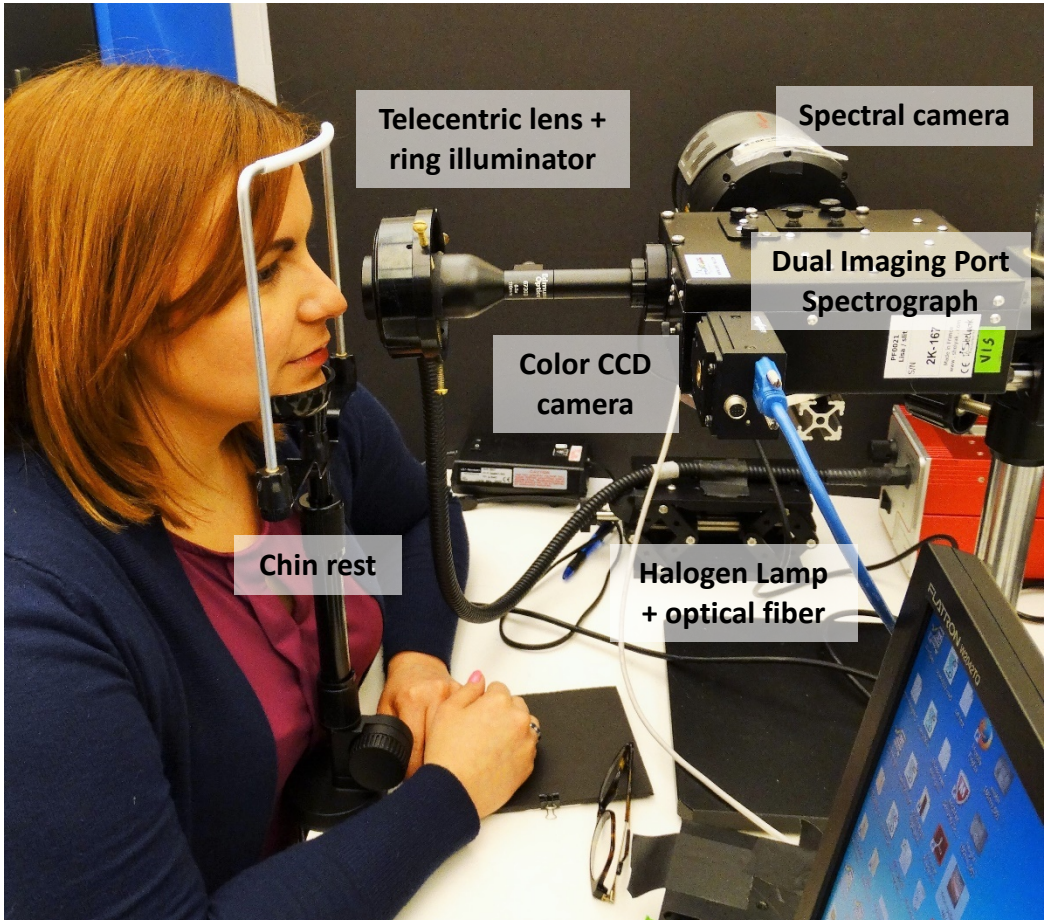
IMAGING INSTRUMENT



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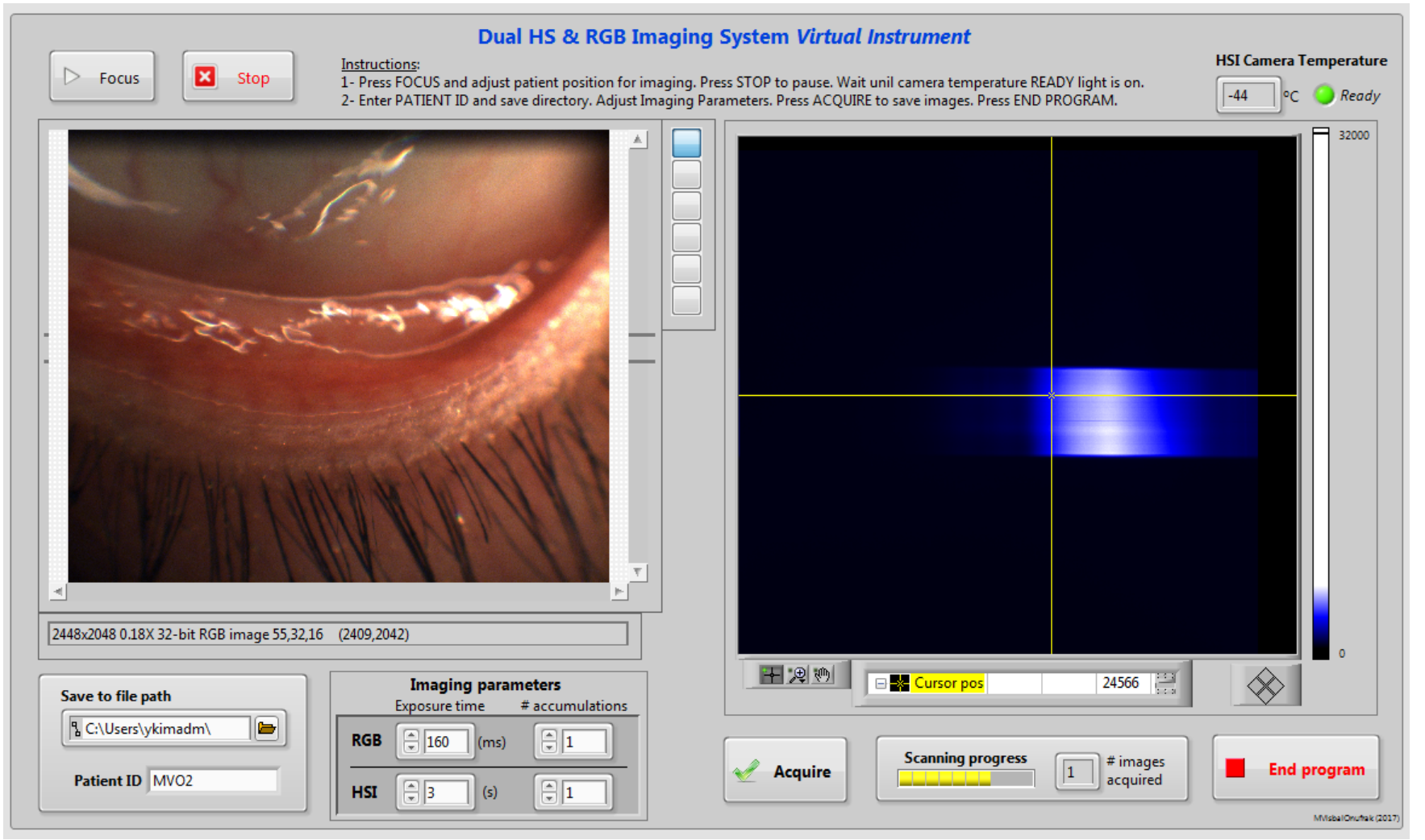
IMAGING INSTRUMENT



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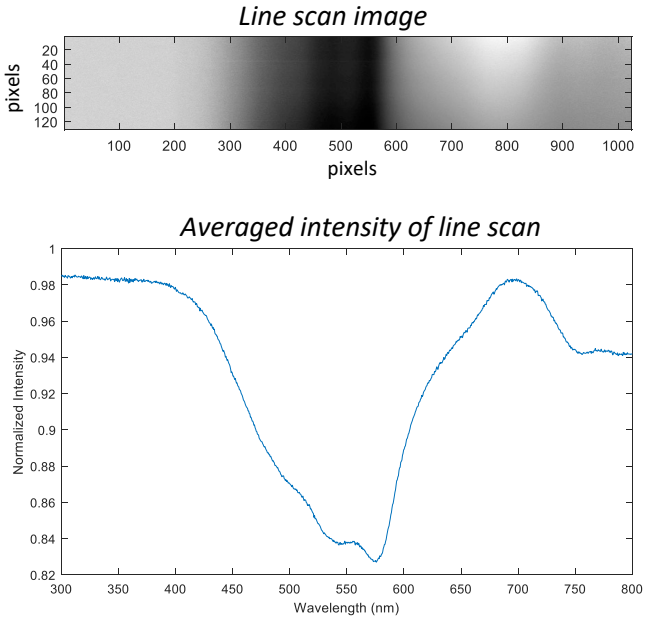
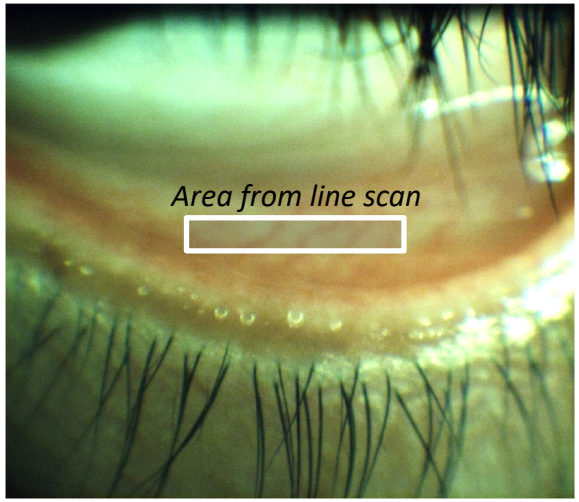
EYELID IMAGING

Hyperspectral



RGB



TAKEN WITH SMARTPHONE CAMERA

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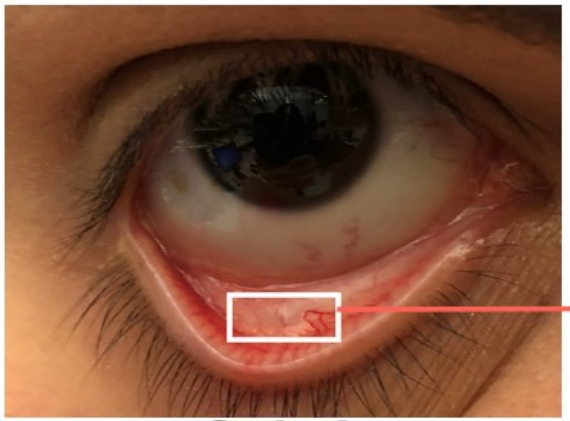
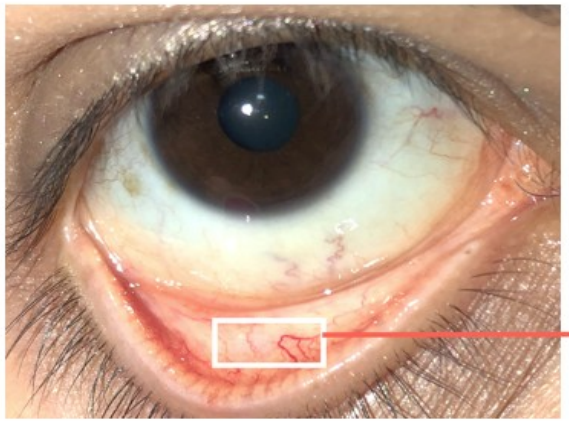
REGION OF INTEREST



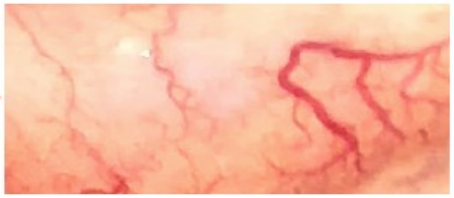
Sub-A



ROI=Cropped image

Eyelid (Flash Off)

Eyelid (Flash On)

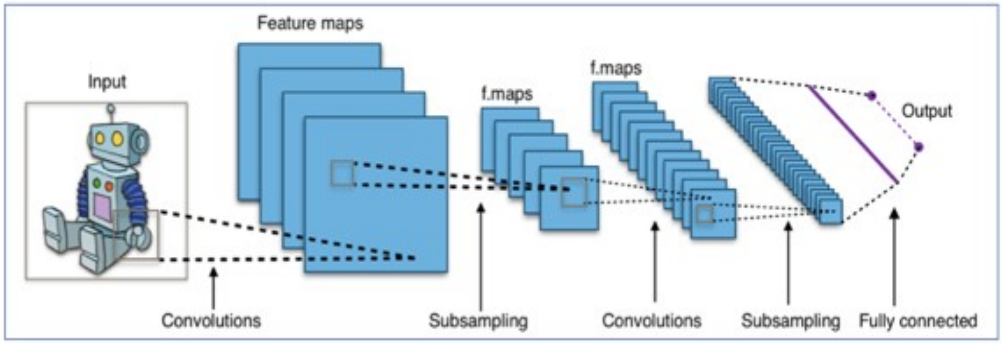


CNN

ConvNet is
- a class of deep, feed-forward artificial neural networks
- successfully been applied to analyzing visual imagery
- makes the explicit assumption that the inputs are images

There are three main types of layers:
- Convolutional Layer,
- Pooling Layer, and
- Fully-Connected Layer.

*We will **stack these layers** to form a full **ConvNet** architecture



CONV layer:
- compute the output of neurons
- computing a dot product
- between their weights and a small region

POOL layer:
- perform a downsampling operation
- along the spatial dimensions (width, height)

Fully-connected layer
- compute the class scores
- where each of the 10 numbers correspond to a class score (for 10 categories)

CNN

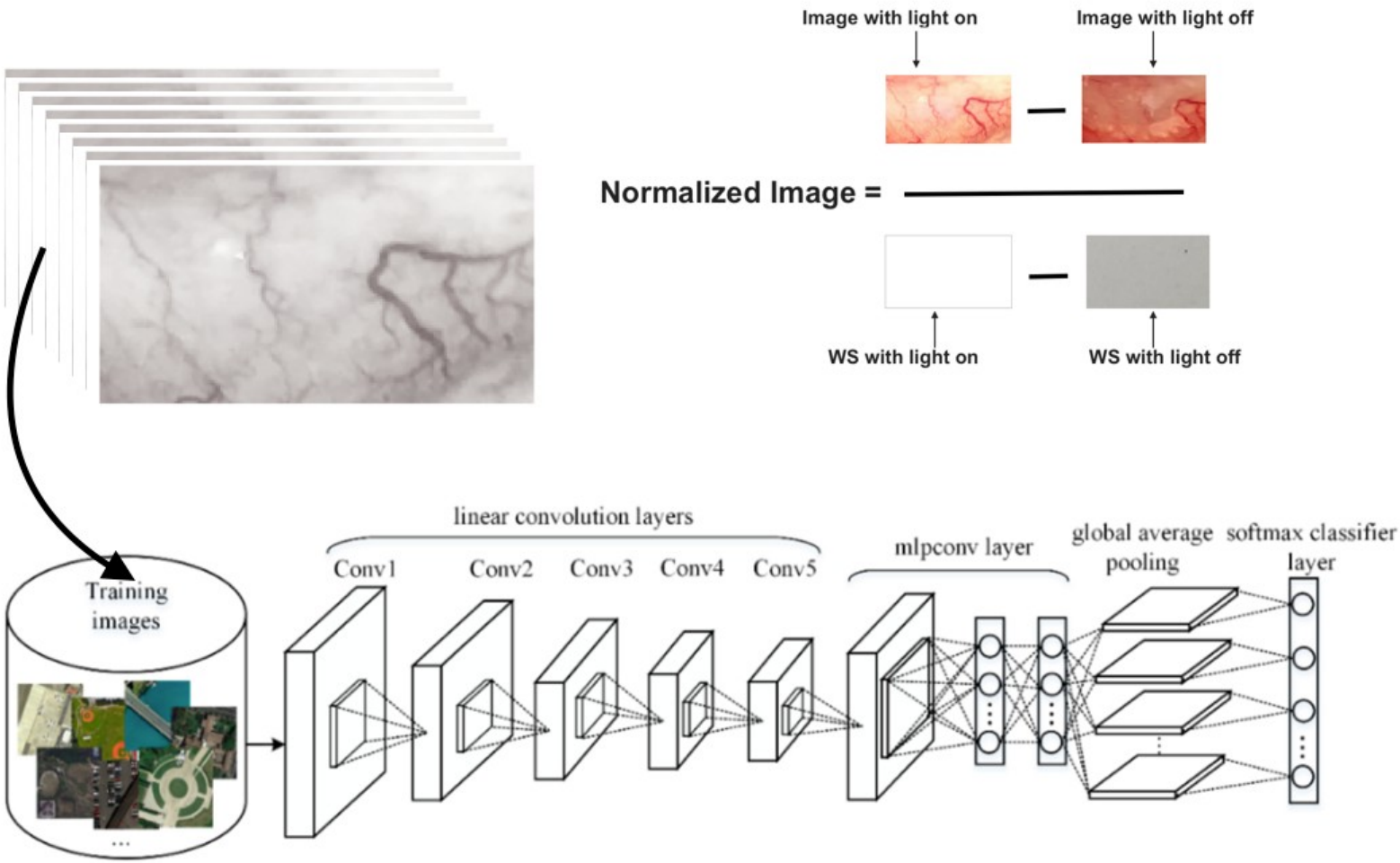


Image with light on
Image with light off
Normalized Image =
WS with light on
WS with light off
Training images
linear convolution layers
Conv1
Conv2
Conv3
Conv4
Conv5
mlpconv layer
global average pooling
softmax classifier layer

CURRENT STATUS

- Moi University Kenya
- 60 subjects
- System and 3 phones
  - Samsung Note 8 plus
  - Iphone 8 plus
  - Samsung J3
- IU Simon and Melvin Cancer Center
  - 144 subjects

DIAGNOSIS-BASED DEMAND SENSING AND DIGITAL TRACKING (DBDD)

- Every two minutes, a mother dies from preventable causes related to childbirth
- 99% of maternal deaths occur in developing countries, and complications from pregnancy and childbirth are leading cause of death among girls age from 15-19
- The UN Commission on Life-Saving Commodities for Women and Children, identified a list of 13 commodities that could save the lives of more than 6 million women and children

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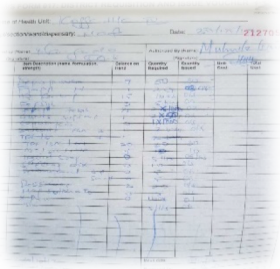
PROBLEM STATEMENT

- Impacts system responsiveness to the needs of lower-level health facilities with paper-based reporting and requisition systems.
- Pharmaceutical supply stock-outs and expired medications weaken overall health systems' abilities to respond to healthcare needs and put MCH at risk.
- Findings from Kojja health center IV at Mukono district:
  - Requires 2-3 days to prepare the bi-monthly orders
  - Replication of the same information in different register books
  - Predicting future orders just by guessing results in unusual stock-out or over-stock
  - Lack of stock management system to monitor lab test commodities



Acquisition form of medical commodities

Paper-based antenatal patient registers

Medication expired in December 2017

Refrigerated medication stock out

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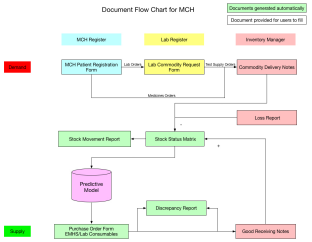
DBDD

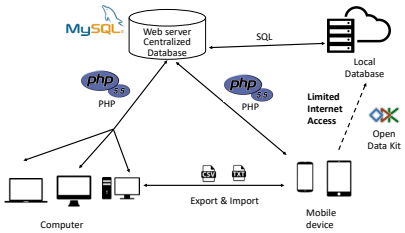
- Target Group: Maternal and Child Health (MCH)
- Needs:
  - Increase availability and timely access to supplies reporting and requisition systems
  - Reduce the cases of supplies stock-out and overstock of targeted medical supplies
  - Improve patients outcome (e.g. reduction in maternal mortality rate, quality of prenatal care)
- Why:
  - Lack of digitalized supply management system impedes the access to data for timely-decision making
  - Pharmaceutical supply stock-outs and expired medications
- Solutions: Diagnosis-Based Demand sensing and Digital tracking (DBDD) approach
  - Analyze the process of information flow to identify critical path of supplies associated with MCH in Uganda health system
  - Improve the forecast for MCH commodities by digitalizing critical data sets and triangulating patient data, laboratory data, and stock data

DBDD SOLUTION



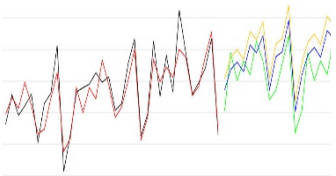
Preliminary Study

- The objective of this phase is to identify the flow of data in terms of the quantity and transaction time of item.
- The output includes the data flow chart by integrating previous documents.



Phase 1 – Automation of Inventory Management

- This phase is for automating the previous inventory management process and collecting the data about the usage of individual items for forecasting demands.
  1. In the initial stage of Phase 1, a basic inventory management system based on safety stock levels will be implemented and tested.
  2. Based on the result, the demand forecasting for each item will be included at the end of Phase 1.



Phase 2 – Prediction of Demands

- This phase is for predicting required order quantities and updating order strategies based on the data of patients and their arrivals.

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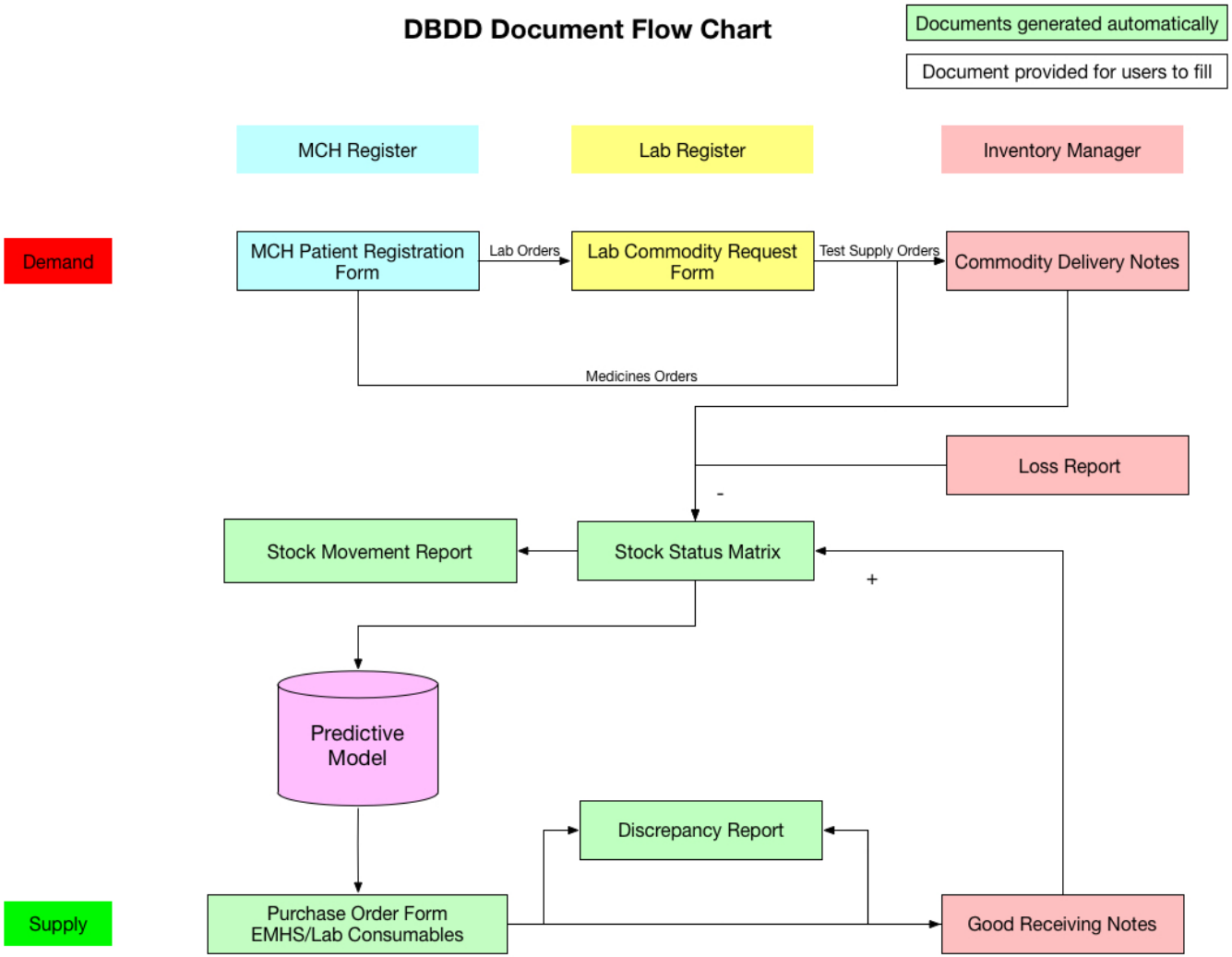
DOCUMENT FLOW CHART



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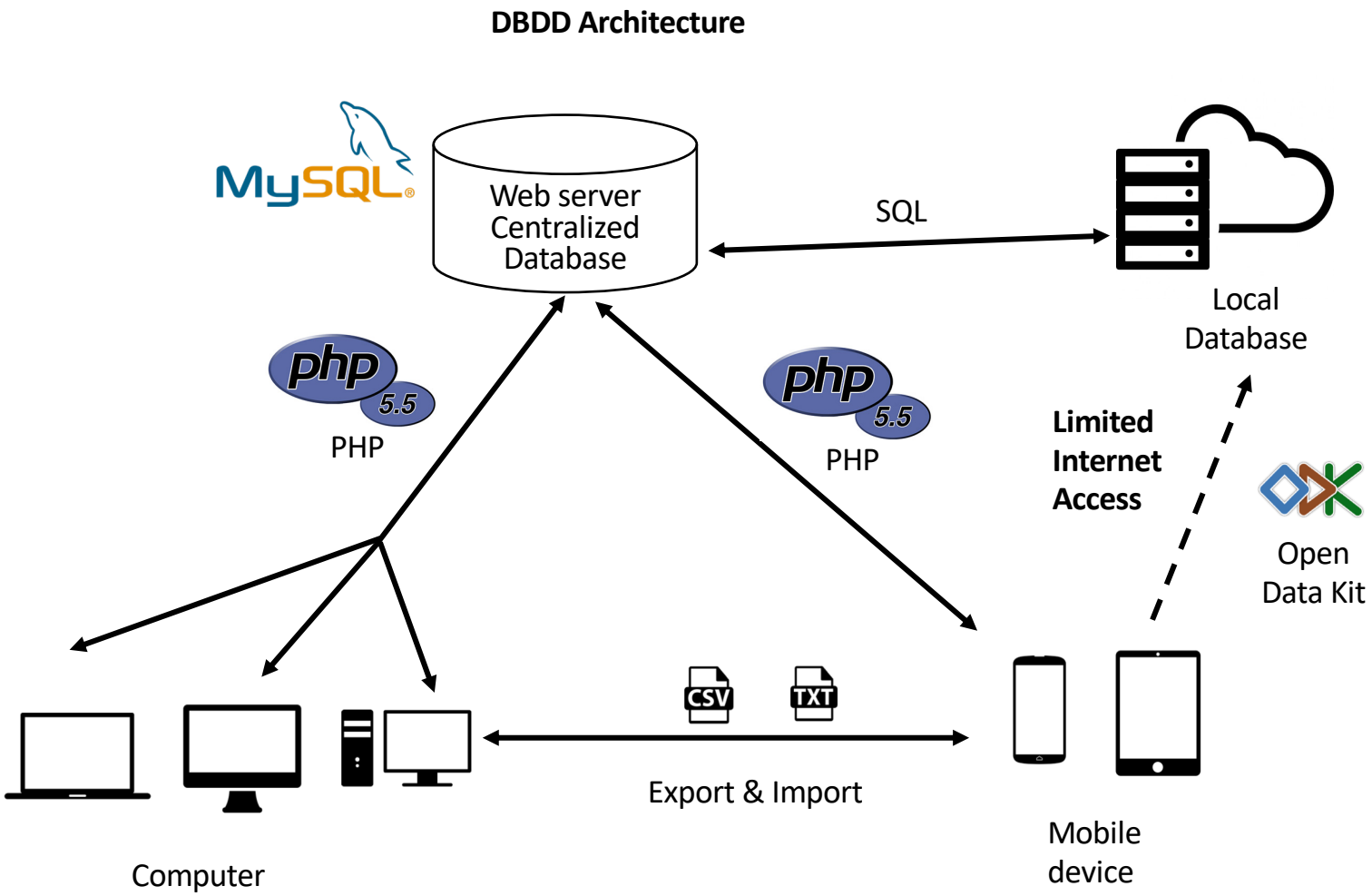
DBDD ARCHITECTURE



COMPETITIVE ADVANTAGE

- Prompt frontline stakeholders to generate efficient, reliable and sustainable distribution with the real time data
- Reduce the time needed to prepare orders
- Reduce the cases of stock-out and overstock of targeted medical supplies
- Improve patient outcomes by reducing maternal, infant and under-5 mortality rate through increasing commodity availability
- Serve as a proof of concept for replacing the current paper-based system (involving multiple register books with lots of duplicate entries) with single entry digital system

SUSTAINABILITY

The Process of Improvement

Capability and Understanding

- Triangulation of three key data sets: antenatal register delivery book, stock cards together with the essential supplies for MCH to optimize ordering practices in primary care facilities
- Digitization of critical aspects of key data sets to greatly simplify its capture and management at primary care facility level
- Establishment of predictive models that calibrate based on real-time data along with ensuring higher level decision making through the use of cloud based platform

Commitment

- Provide valuable evidence concerning the applicability, advantages, and disadvantages of establishing electronic systems for use at health center IV level
- Collaborate with major partners and align our project with other similar initiatives and existing systems (UgandaEMR, MSH's Rx solutions) to add value instead of repeating what is already done

Partnership

- Ministry of Health (MOH)
- Monitoring and Evaluation Technical Support Program (METS)
- National Medical Stores (NMS)

MCARE: MOBILE BASED AUTISM CARE

- Design and build mCARE, that will allow caregivers to routinely report, and thus build the personal records of behavioral progress for each child with ASD
- Improve and expedite the decision making process of the care practitioners by building appropriate visualization tools to summarize this information
- Assess the impact of mCARE on treatment and management practices around ASD care in Bangladesh.

METHODOLOGY

- Total 300 participants (2-9 years)

	NIMH	IPNA	Nishpap	AWF
mCARE-SMS	50 (C)	50 (C)		
mCARE-APP	50 (C)	50 (C)	50 (C)	50 (C)
mCARE-DMP	5 (P)	5 (P)	3 (P)	3 (P)
Status	Public	Public	Private	Private
Location	Dhaka	Dhaka	Chittagong	Dhaka

FUNCTIONALITY

- mCARE-APP
  - Behavioral parameters
  - Milestone parameters
  - Bi-weekly report
  - mCARE-DMP log in
  - Emergency SMS
- mCARE-SMS
  - Behavioral parameters
- mCARE-DMP
  - Longitudinal view
  - Multi-parameter comparison
  - Pre-defined triggers
  - Response SMS

SECONDARY DATA ANALYSIS ON MOZAMBIQUE OPENMRS DATASET

- Global scale-up of antiretroviral therapy has been the primary contributor to a 48% decline in deaths from AIDS-related causes
- Roughly 55% (41%-63%) of 1800,000 people living with HIV in Mozambique are accessing antiretroviral therapy in 2016
- The retention rate (i.e., patients remaining in care and on ART) is 75%, 48% and 37% after one, two, and three years respectively
- UNAIDS goal: 90-90-90 (diagnose, ART, viral suppression)
- The goal is to improve the retention of patients on ART through identifying patients with risk to fail in the first line ART adherence
  - To use machine learning techniques to predict risk of treatment failure
  - To use machine learning techniques to predict lost to follow up and adherence

DATA (OPENMRS)

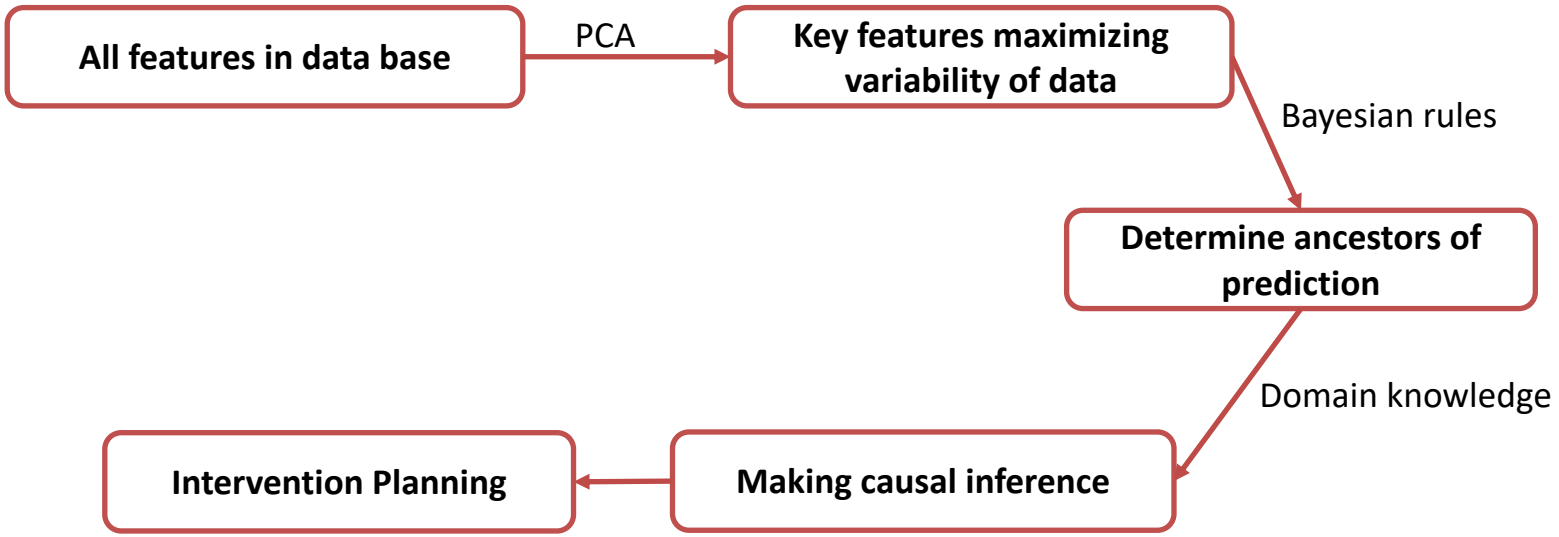
- OpenMRS is a scalable, user-driven, open source medical record system platform that helps to improve health care delivery in resources constrained settings
- 120k HIV patient data
- Only one or two countries out of 54 African countries utilize OpenMRS dataset to predict ART adherence
- OpenMRS data possess huge potential to be utilized for secondary analysis as well as developing predictive models on important outcome measures for LMIC settings

PROPOSED METHODOLOGY

- Utilize both supervised learning and unsupervised machine learning to map out key characteristics in predicting adherence behavior of patients receiving first line ART treatment
- Identify critical features from data dictionary and use them as input to supervised learning models
- Choices of supervised models
  - Multiple linear regression
  - Support vector machine
  - Bayesian classifier
  - Artificial neural network
- Choices of unsupervised models
  - K-means clustering
  - Principle component analysis
- Develop Bayesian network to enhance the quality of risk stratification method

PROCESS FLOW

- One of the objectives of our research: intervention planning for patients with high risk failing first line ART regimen
- Identify the features in data dictionary or database
- Adopt features selection principles (PCA, K-means) to extract key features that maximize the variability of data
- Utilize Casual Bayesian network for efficient intervention planning



STATISTICAL ANALYSIS PLAN

- Associations between socio-demographic or HIV-related variables and virological failure will be assessed by chi-square test for categorical variables and the Student's t-test for continuous variables
- Univariate logistic regression analysis will be used to identify factors associated with adherence behavior and virological failure
- N-fold cross validation
- Multi-level regression models will be used to identify individual level (i.e. sex, BMI, age, educational level, marital status, etc.), district-level, health facility-level and contextual-level (location – urban vs. rural, etc.) variables associated with viral suppression

REMEDI – MONITORS/VENTS

REMEDi MEMBER HOME COMMUNITY LABS CATALYZECARE ABOUT ACCOUNT HELP

APPS Monitors / Vents: Settings My Hospital

Monitor ▸ Settings in **My Hospital** compared with All 20 Hospitals ▸

Primary Population / Care Level: **Neonatal / ICU (High)** ▸ Alarm Cutpoints | Alarm Priorities

Alarms: All ▸ Filters: None ▸

My Hospital State: IN | Beds: 500+ | Altitude: 0 - 5,000ft | Urban, Academic/Teaching Updated: May 15, 2017

Alarm	Unit (Level | Profile) / Priority		Priority Distribution in Population
	IV | < 34 weeks	IV | >= 34 weeks	Crisis / Critical / High / Warning / Medium / Advisory / Low / Other
Apnea	High	High	100% 100%
Asystole	High	High	92% 100%
Brady	High	High	60% 100%
SpO2 Leads Off	High	High	60% 100%
EKG Leads Off	High	High	60% 100%
Vfib/Vtach	Medium	Medium	60% 100%
V Tach	Medium	Medium	60% 100%
V Brady	Medium	Medium	60% 100%
Pause	Medium	Medium	75% 100%
Trigeminy	Low	Low	75% 100%
R on T	Low	Low	100% 100%
PVC	Low	Low	100% 100%

Procuring → Prescribing → Transcribing → Dispensing → Administering → Monitoring

REMEDi CENTRAL

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PHYSIOLOGICAL MONITOR INFORMATICS

- **Phase 1:**
  - Document of agreed upon terms for physiological parameters
  - Document of default values, soft limits and hard limits (where applicable) of physiological parameters categorized by different vendors
  - Document of default values, soft limits and hard limits (where applicable) of physiological parameters categorized by different profiles and hospitals
- **Phase 2:**
  - Develop a protocol for collecting alarms from monitor devices
  - Design and develop a database for physiological parameter alarms
  - Develop the analytical and visualization tool based on the collected alarms
- **Phase 3:**
  - Develop a protocol for collecting physiological parameter values from the monitors
  - Start building a 24/7 database based on selected physiological parameters
  - Promote evidence based community of practice

ACKNOWLEDGEMENT

MAKERERE UNIVERSITY

NIH
National Institute
of Mental Health

BILL & MELINDA
GATES foundation

I²D LAB

NIH
Fogarty

Geisinger Caring

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