



Affordable Sensing based Healthcare

- Screening and Therapy for Masses

Arpan Pal
Head, Embedded Systems and Robotics
TCS Research and Innovation
Tata Consultancy Services, India

Problems of the New Age and the New World



Developed Countries

**Elderly people - 44.7 M (2013),
double by 2060**

Invasive and costly diagnosis

**One size fits all Diagnostic /
Treatment protocols**



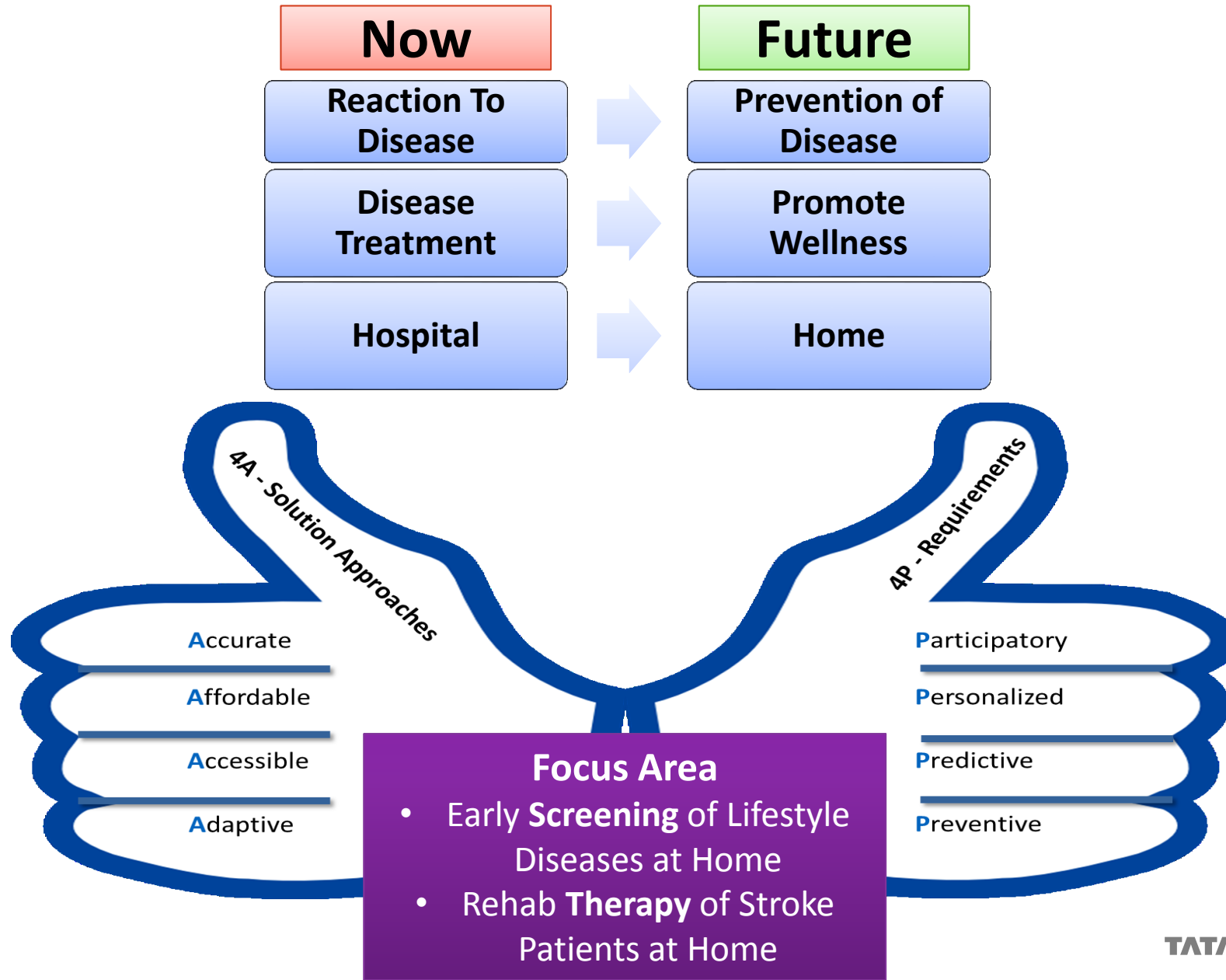
Developing Countries

**Capacity - not enough doctors
per patient**

**Reachability – specialized
primary care not available**

**Affordability - majority cannot
afford to pay the cost**

Next Generation Health





Screening for Lifestyle Diseases

CAD – Motivation

• Indians with Coronary Artery Disease (in millions)

Age	2010*	2015**	Increase from 2010 to 2015 (%)
All	47.0	61.8	32
<50 yrs of age	28.4	37.3	31
<40 yrs of age	17.4	23.0	32
<30 yrs of age	8.3	10.5	27

- * - 780 million adults > 20 years of age
- ** - 800 million adults > 20 years of age

- National Commission on Macroeconomics and Health.
- Enas EA, Mehta J. Malignant coronary artery disease in young Asian Indians: thoughts on pathogenesis, prevention, and therapy. Coronary Artery Disease in Asian Indians (CADI) Study. *Clin Cardiol.* Mar 1995;18(3):131-135.

CAD – also a global hazard

IHD [ischemic heart disease, also known as CAD] . . . is likely to become the most common cause of death worldwide by 2020 - Antman et al., 2008

Existing conclusive diagnostic procedure - coronary angiogram - invasive, potentially harmful, costly.

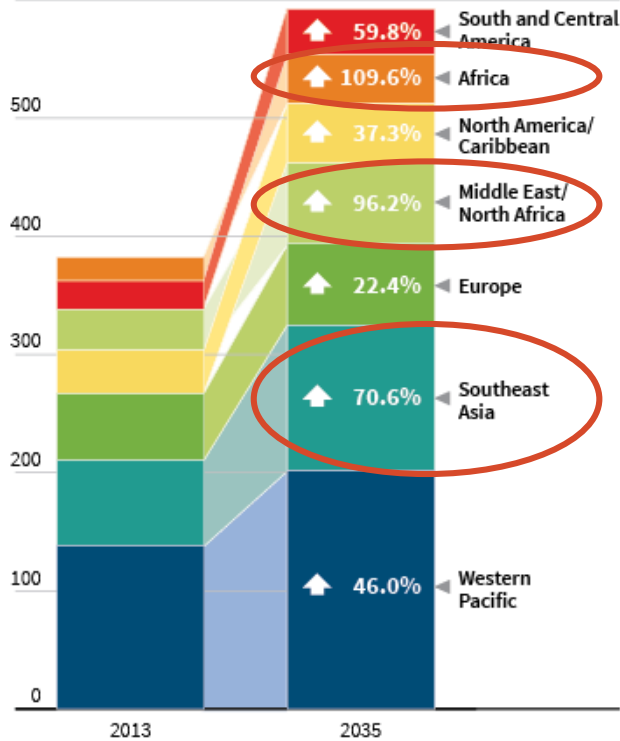
South Asians typically have smaller coronary artery diameters than Caucasians (3.2+/-0.56 mm vs. 5.53+/-0.69 mm) <http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1741307/pdf/v075p00463.pdf>

Need for Early Screening by detecting/predicting early onset of CAD

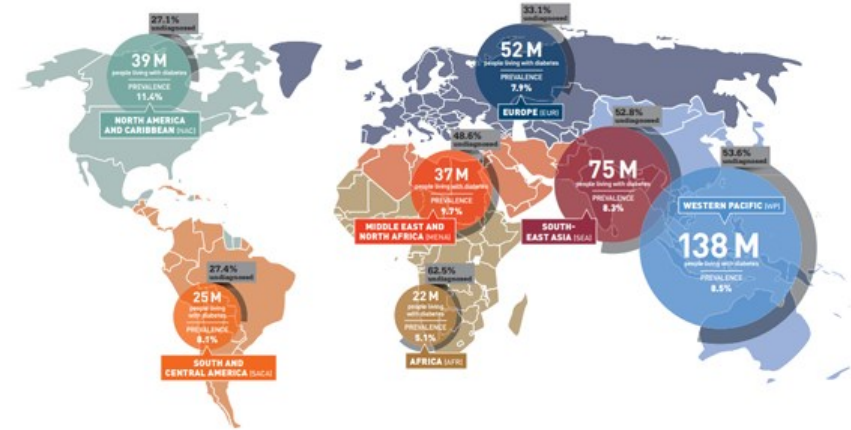
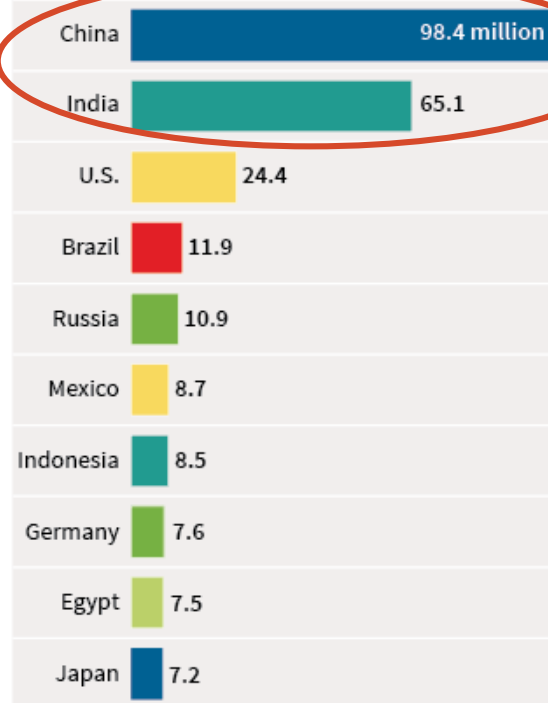
Diabetes – Motivation

World diabetes cases expected to jump 55 percent by 2035

Current and projected cases of diabetes by region
600 million



Top 10 countries by number of people with diabetes in 2013, ages 20 to 79



- The global prevalence of diabetes* among adults over 18 years of age has risen from 4.7% in 1980 to 8.5% in 2014
- **In Indian sub-continent itself there are 75 Million Diabetes cases - it will rise to 140 Million by 2035 .**
- Diabetes resulted in 5 Million deaths in 2015 worldwide and **75% of diabetes people live in low and middle income countries.**

Source "World Health Organization"

Source: International Diabetes Federation

S. Culp, 12/11/2013

REUTERS

Manageable if detected early, preventable if detected in pre-diabetic stage

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Hypertension – Motivation

India – Maternal Mortality Rate per 100K Live Berths

2011	2012	2013	2014
206	197	189	181

Singapore–10, USA -14, UK - 9

data.worldbank.org/indicator/SH.STA.MMRT

Causes of maternal deaths		
1.	Direct Causes:	81%
	Severe Bleeding	25%
	Sepsis	15%
	Unsafe abortions	13%
	Eclampsia	12%
	Obstructed Labour	8%
	Other direct causes *	8%
2.	Indirect Causes **	19%

* Other direct causes: Ectopic pregnancy, embolism, anesthesia related.
 ** Indirect Causes: Malaria, Anemia, Heart Diseases.

Hypertension – also a global hazard

USA Figures

- Hypertension - leading cause of heart disease and stroke
- 1/3rd have hypertension, another 1/3rd **prehypertension**
- Only **54%** of hypertensive people have it under control
- Total cost to Healthcare - **US\$48.6 billion** each year.

http://www.cdc.gov/dhdsp/data_statistics/fact_sheets/fs_bloodpressure.htm

Eclampsia - a condition in which one or more convulsions occur in a pregnant woman suffering from high blood pressure, often followed by coma and posing a threat to the health of mother and baby.

Rehana Kausar, “Maternal Mortality in India - Magnitude, Causes and Concerns”, Indian Journal for the Practising Doctor, Vol. 2, No. 2 (2005-05 - 2005-06)
<http://www.indmedica.com/journals.php/mail?journalid=3&issueid=58&articleid=722&action=article>

Need for Early Screening of Hypertensive Mothers – control of Hypertension by medication significantly reduces complications

Also need for Hypertensive Screening in general

Our Approach towards a Frugal Solution

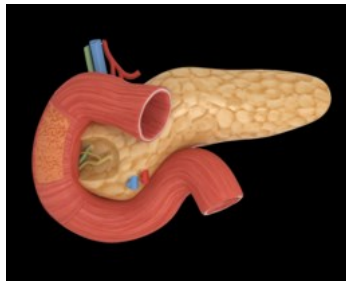


HeartSense - Accurate, Affordable, Accessible, Adaptive diagnostics & screening

Coronary Artery Disease (CAD)



Diabetes



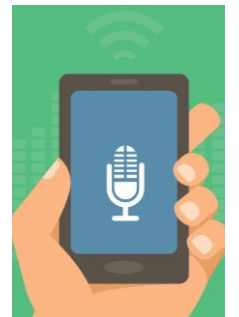
Hypertension



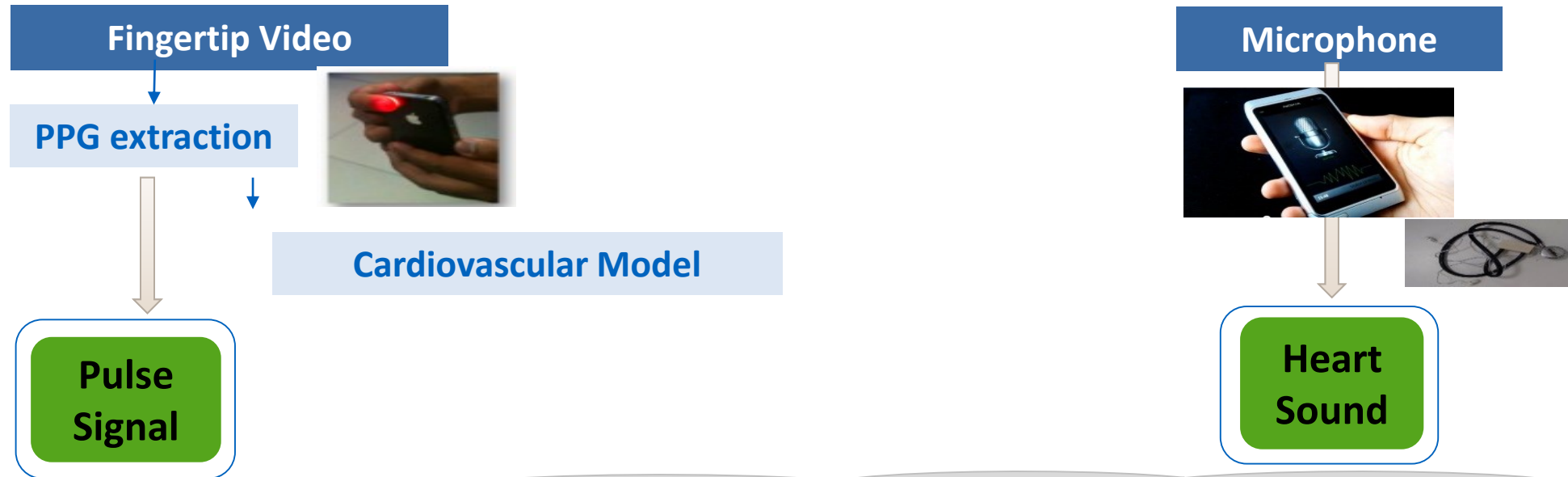
Need for India

- At people fingertips – Capacity and Reachability
- Low-cost – Affordability

Use only sensors on smart phones and low-cost attachment to smartphones



Solution Architecture



IoT Platform on the Cloud

Expert Doctor



Advanced Analytics

Real-time View

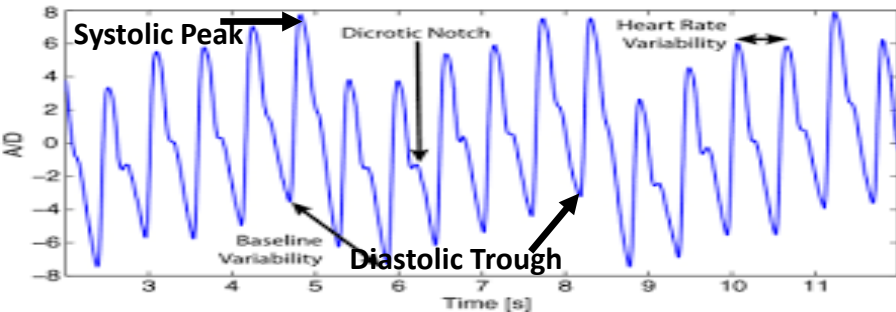
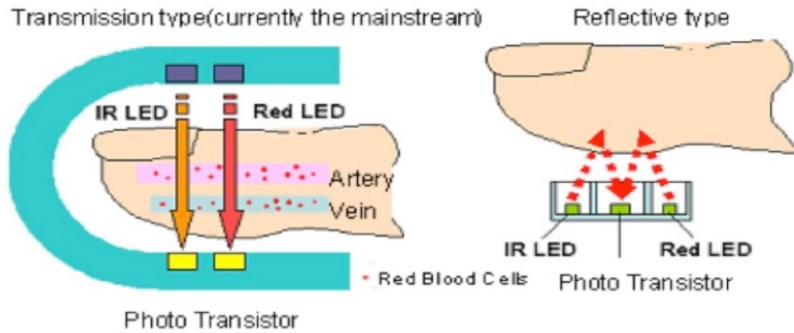
Event Alerting

Screening –
CAD, Diabetes,
Hypertension

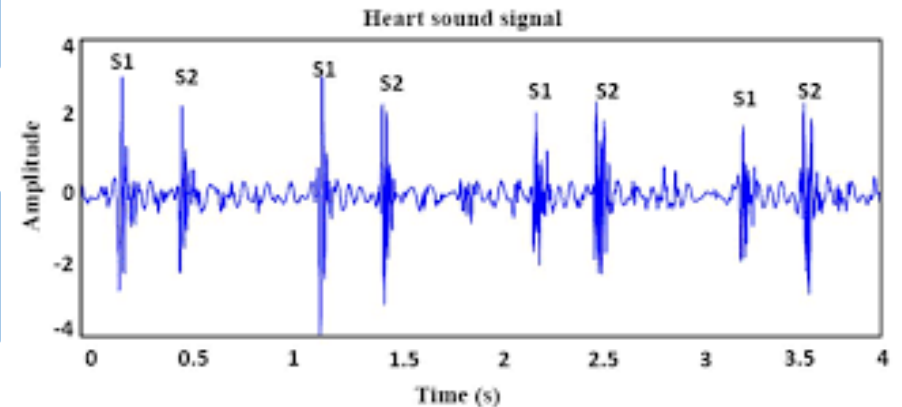
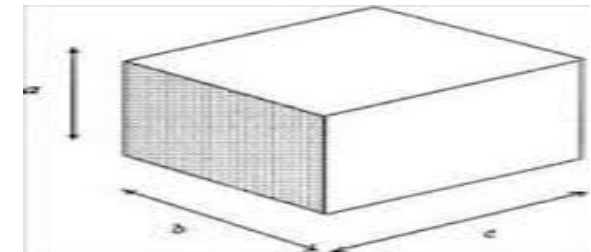
Prevent Disease, Promote Wellness, Inclusive

HeartSense Technology

Photoplethysmogram (PPG)



Phonocardiogram (PCG)



Acquisition and Pre-processing

Feature Engineering and Extraction, Cardiovascular Models

Classification (includes metadata like age, gender, height, weight, BMI)

Statistical Post-processing

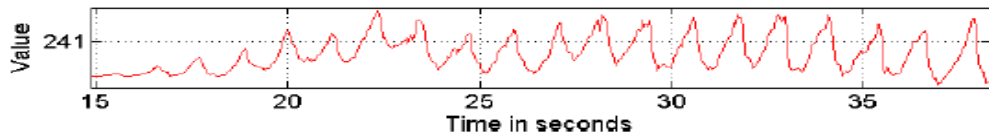
"Effects of Fingertip Orientation and Flash Location in Smartphone Photoplethysmography", ICACCI 2014

"Design And Simulation Of A Low-cost Digital Stethoscope", COMSOL 2015

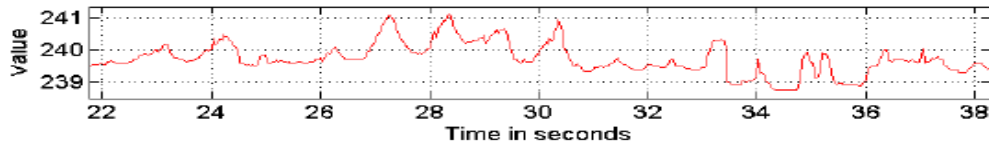


Noise Cleaning for PPG and PCG obtained from Mobile Phones

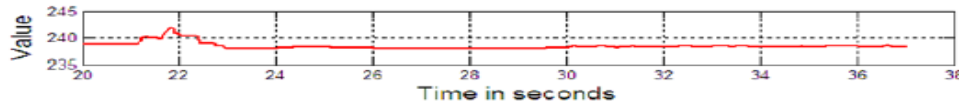
Photoplethysmogram (PPG)



(a) Good capture

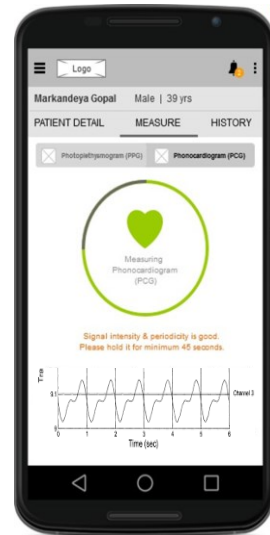
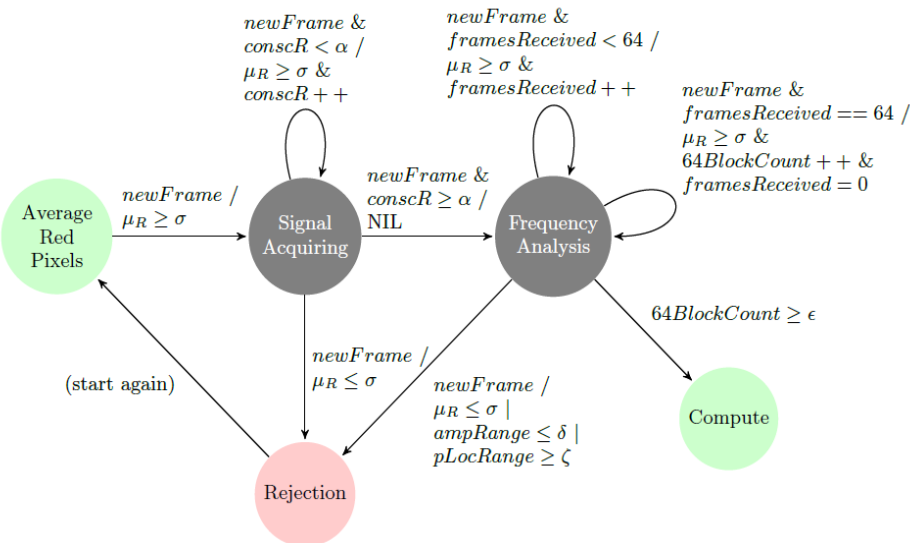
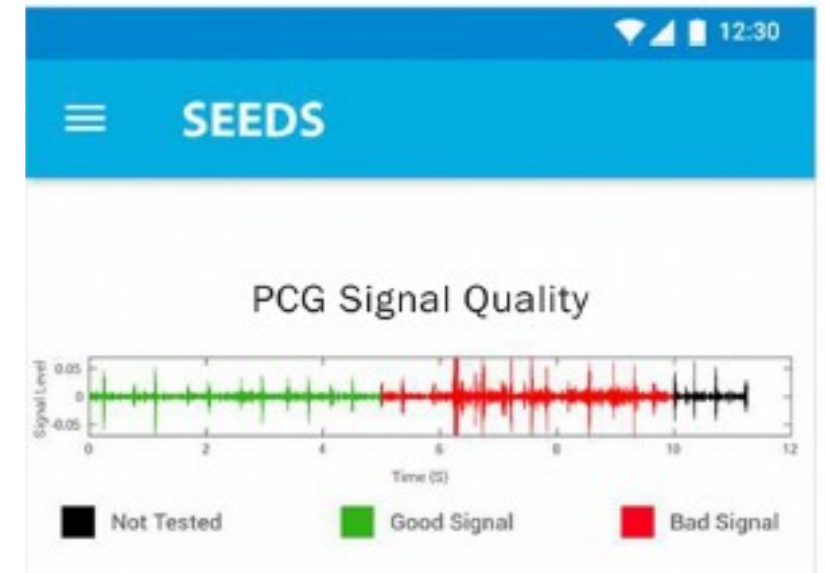
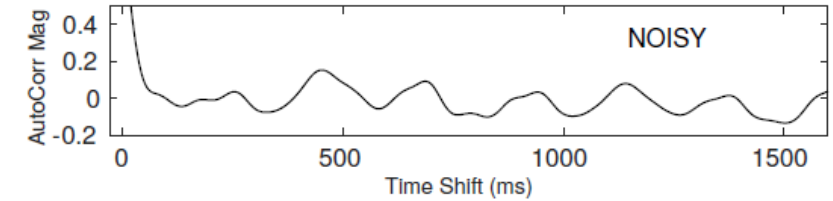
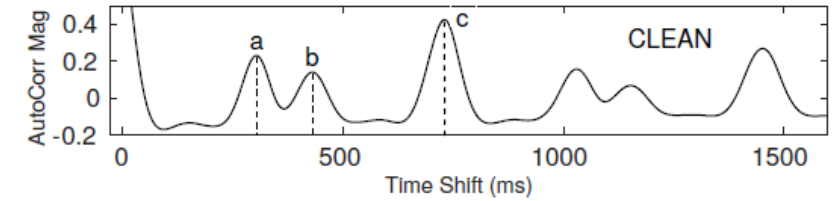


(b) Motion artifacts



(c) Improper placement of finger

Phonocardiogram (PCG)



"Novel Peak detection to estimate HRV using Smartphone Audio" BSN 2015

"Noise Detection In Smartphone Phonocardiogram", ICASSP Demo 2017, Submitted

"A robust heart rate detection using smart-phone video." ACM MobiHoc workshop on Pervasive wireless healthcare, 2013.

CAD – Pilot Study Results

Own Collected dataset (15 non-CAD + 10 CAD)

- 10 healthy adults with no known history of cardiac problem at TCS Kolkata
- 5 aged non-CAD patients from Fortis Kolkata)
- 10 angio-proven CAD from Fortis

MIMIC-II / Physionet dataset

- 56 CAD and 56 non-CAD (PPG)
- 296 CAD and 2840 non-CAD (PCG)

	Own Collected Data		MIMIC-II / Physionet Data	
	Specificity	Sensitivity	Specificity	Sensitivity
PCG	80%	70%	90%	80%
PPG	70%	90%	82%	88%
Fusion	80%	93%	-	-

80-20 k-fold validation

Sensitivity = correctly identify CAD

Specificity = correctly identify non-CAD

Future Plan

- 1000 patient trial to be started in Fortis Hospital, Kolkata, India
- IRB clearance in place

"Time-Frequency Analysis of Phonocardiogram for Classifying Heart Disease", Computing in Cardiology 2016

"Identifying Coronary Artery Disease from Photoplethysmogram" in IoPH Workshop, UbiComp 2016

"A Multi Sensor Fusion Approach for Non invasive Detection of Coronary Artery Disease", BHI 2017, Communicated

Indicative Features:

HRV time statistic and frequency spectrum, PPG waveform morphology, PCG (S1-S2) spectrum and statistics



Diabetes Mellitus – Pilot Study Results

Own Collected dataset (AIAMS Hospital, Bangalore, India)

- Sample size: 85x5
 - 24 diabetes subjects
 - 61 Normal Subjects

Diabetic duration:

- 6 Month to 33 years

Future Plan

- 1000 patient trial to be started in Fortis, Kolkata, India
- Work on MIT MIMIC II dataset
- Work on Pre-diabetes
- Peripheral Arterial Resistance Changes also due to Ageing, smoking, hypertension and hyperlipidemia – need for correlation study

Results

- Specificity: 88%
- Sensitivity: 90%

80-20 k-fold validation

Sensitivity = correctly identify DM

Specificity = correctly identify non-DM

Indicative Features:

HRV time statistic and frequency spectrum, PPG waveform morphology

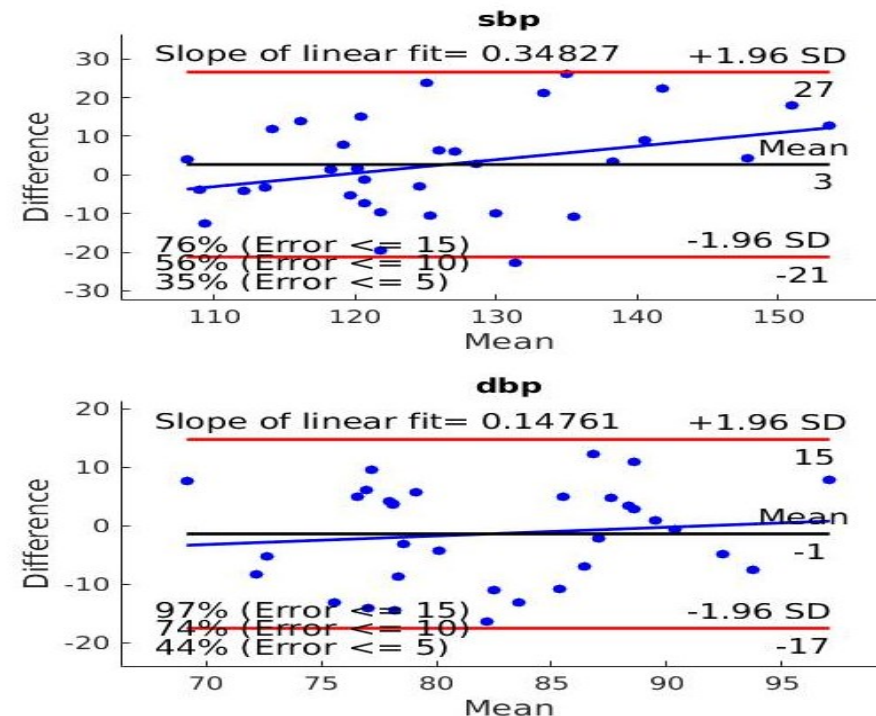
Hypertension – Pilot Study Results

93 subjects (Narayana Nethralaya, Bangalore , Primary healthcare centre, Jamla, Gujarat, TCS Kolkata)

- 68 subjects for training, 58 subjects for testing
- SBP (80-200 mmHg) and DBP (60-130 mmHg)

Error (mmHg)	SBP			DBP		
	OMRON ¹	iBP ²	TCS Model	OMRON ¹	iBP ²	TCS Model
< 5	61%	24%	35%	52%	26%	44%
< 10	85%	44%	56%	85%	48%	74%
< 15	94%	59%	76%	96%	70%	97%

1. El Assaad, Mohamed A., et al. "Validation of the Omron HEM-907 device for blood pressure measurement." *American Journal of Hypertension* 15.S3 (2002): 87A-87A.
2. Plante, Timothy B., et al. "Validation of the Instant Blood Pressure Smartphone App." *JAMA internal medicine* (2016) – A study by Johns Hopkins University School of Medicine



Future Plan

- Focusing more on classification for Hypertensive screening and not on actual BP measurement – MAP based
- Field Trial with Pregnant mothers planned – need for Longitudinal Study

"HeartSense: Smart Phones to Estimate Blood Pressure from Photoplethysmography" ACM Sensys Demo, 2014 - Winner

"Smart Phone Based Blood Pressure Indicator", MobileHealth workshop - Mobihoc 2014

"Estimating Blood Pressure using Windkessel Model on Photoplethysmogram", EMBC 2014

"Blood Pressure Estimation from Photoplethysmogram using Latent Parameters" IEEE ICC 2016

"Noise Cleaning and Gaussian Modeling of Smart Phone Photoplethysmogram to improve Blood Pressure Estimation" ICASSP 2015

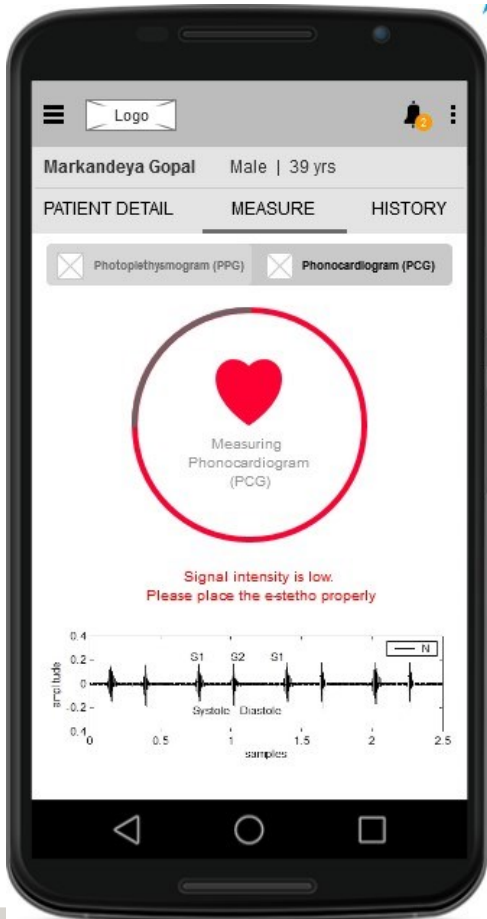
"Robust Blood Pressure Estimation from Smartphone PPG using Statistical Post Processing", BHI 2017, Communicated

"PTT for Estimation of Blood Pressure Using Rough Sets and Support Vector Machine" BHI 2017, Communicated

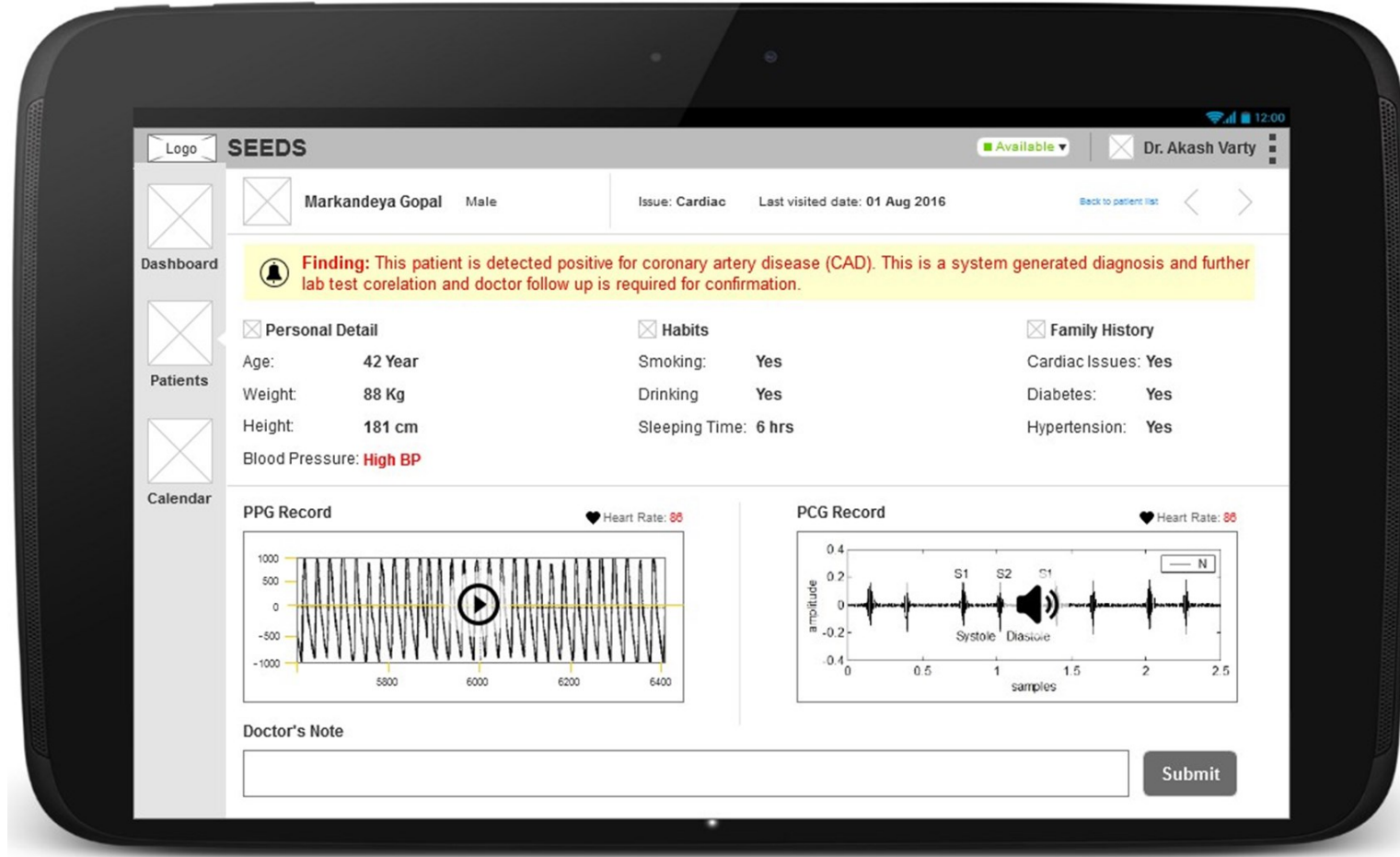
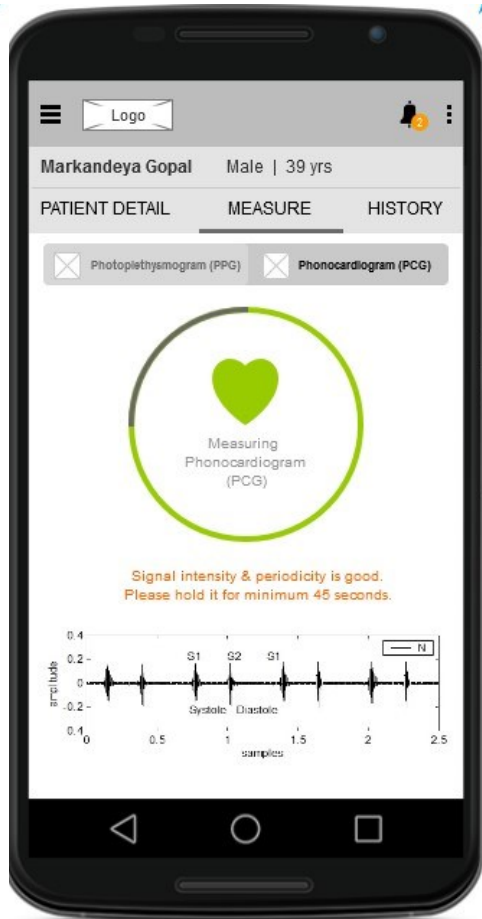
Indicative Features:

Normalized PPG Waveform
Morphology, Age and Body Mass Index (BMI)

Overall Solution



Mobile



Doctor



Therapy for Stroke Patients -Telerehab

Tele-Rehabilitation - Motivation

798 billion

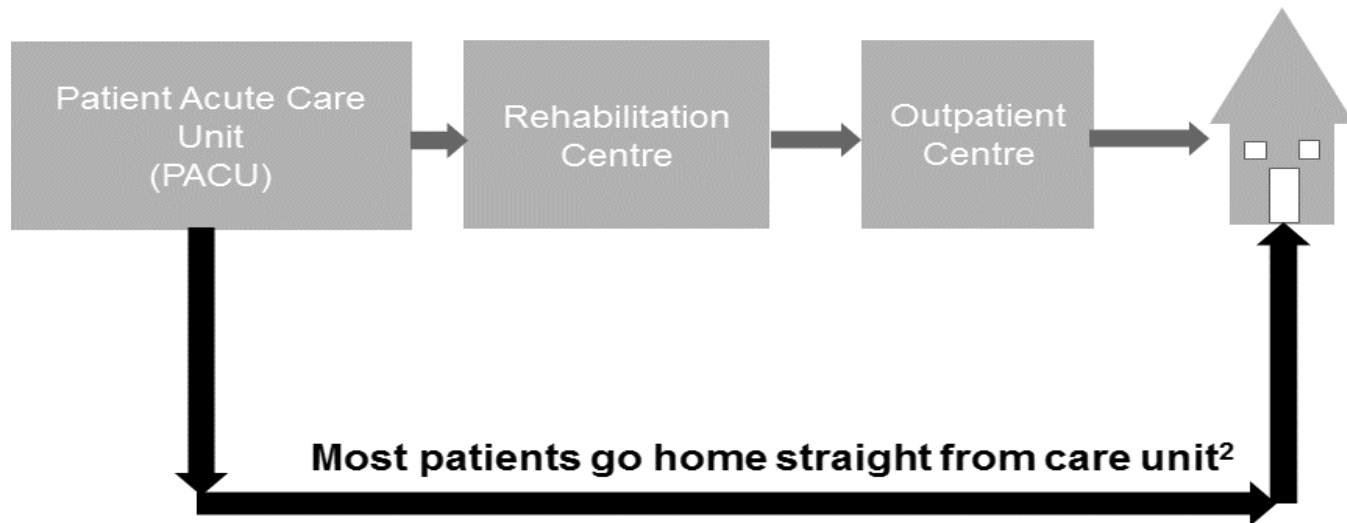
annual cost in EURO in European economy:
twice the cost of cancer¹

1 billion

people worldwide need rehabilitation services¹

2/3

do not receive rehabilitation treatment after discharge¹



India is facing an emerging epidemic of neurological disability

- affecting over 3.5 million people annually
- 11,000 every day
- 7 people/minute



[1] Statistics published and presented at conference RehabWeek 2015 by NeuroAtHome.

[2] <http://www.neuroathome.net/p/home.html>

Expensive devices and high maintenance cost

Devices are not readily available

Limited facilities in rural areas

Diversity in environment, demography and user profiles

Urban patients face transportation challenges

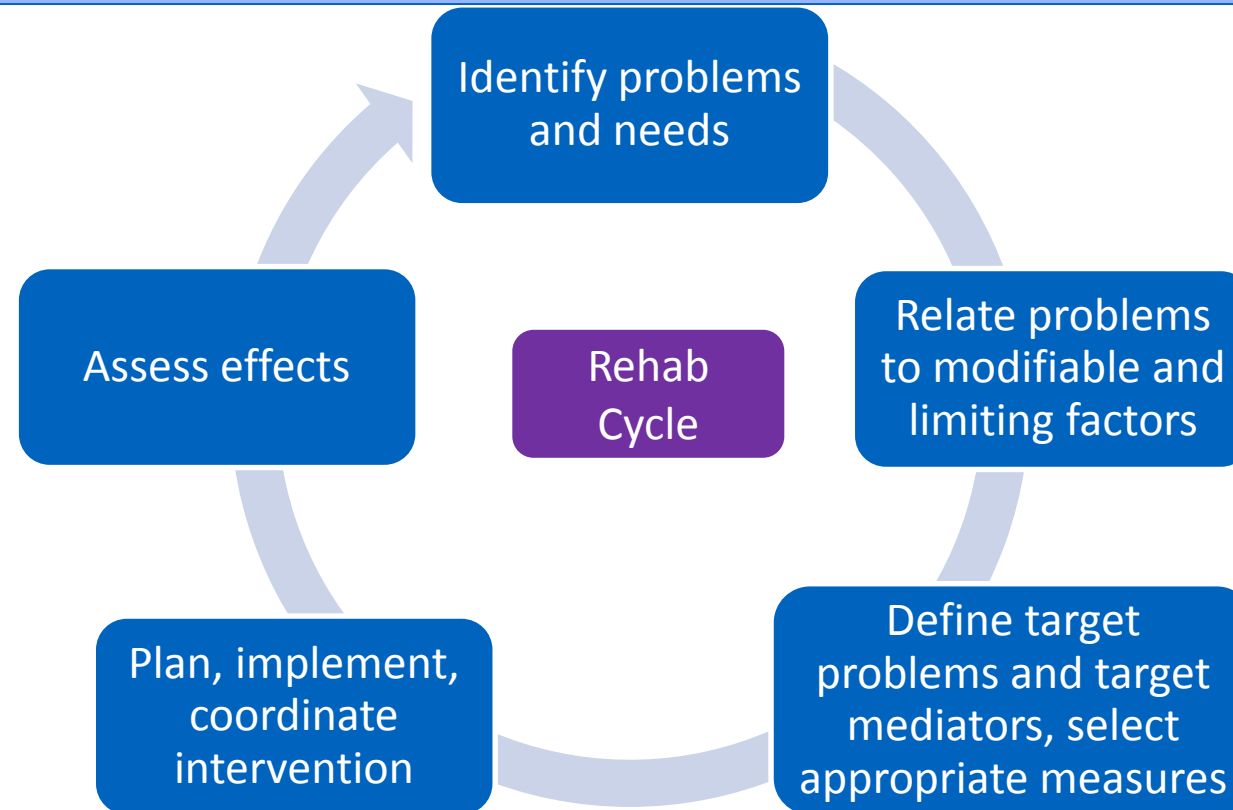
Poor compliance checking

Massive patient footfall at any OPD



Rehabilitation

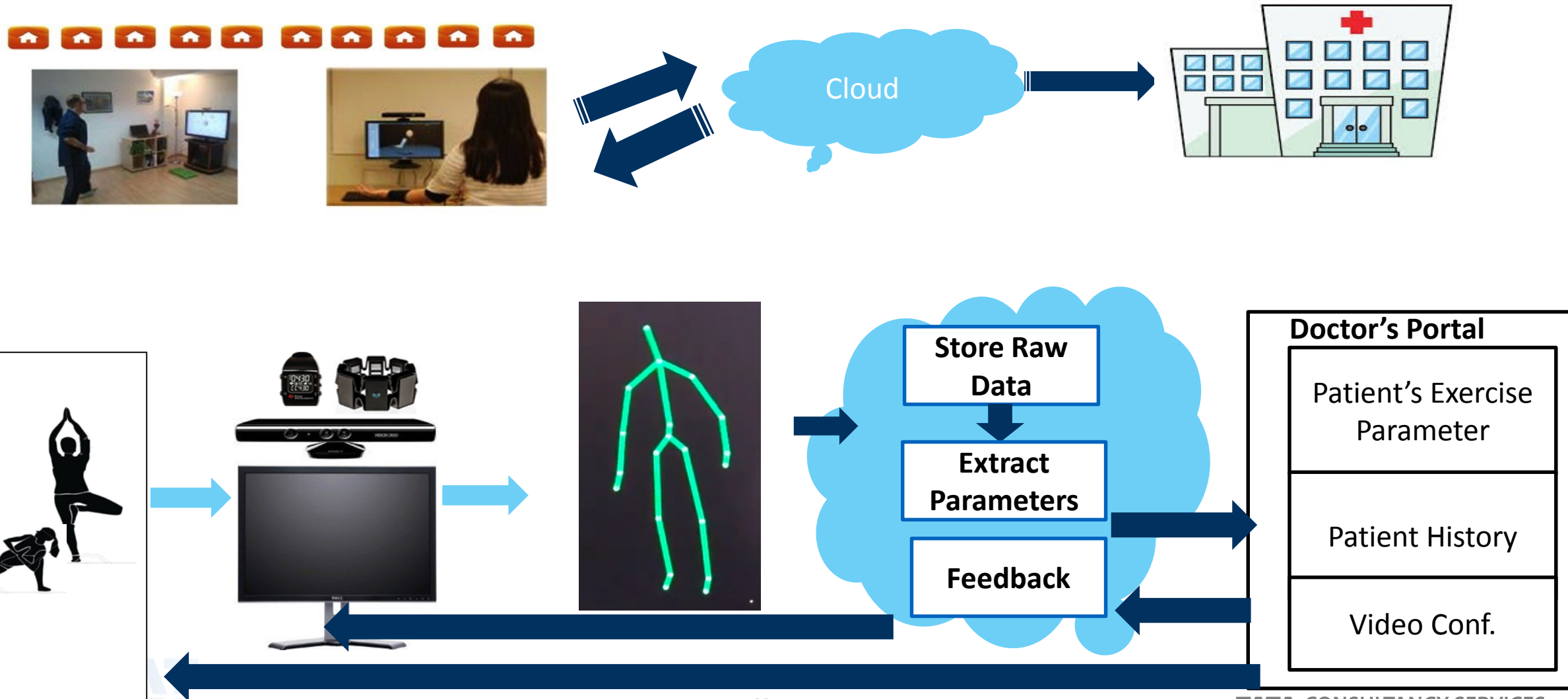
Rehabilitation is the treatment designed to help an individual to restore his/her fullest normal physical, mental, social, vocational and economic capacity.¹



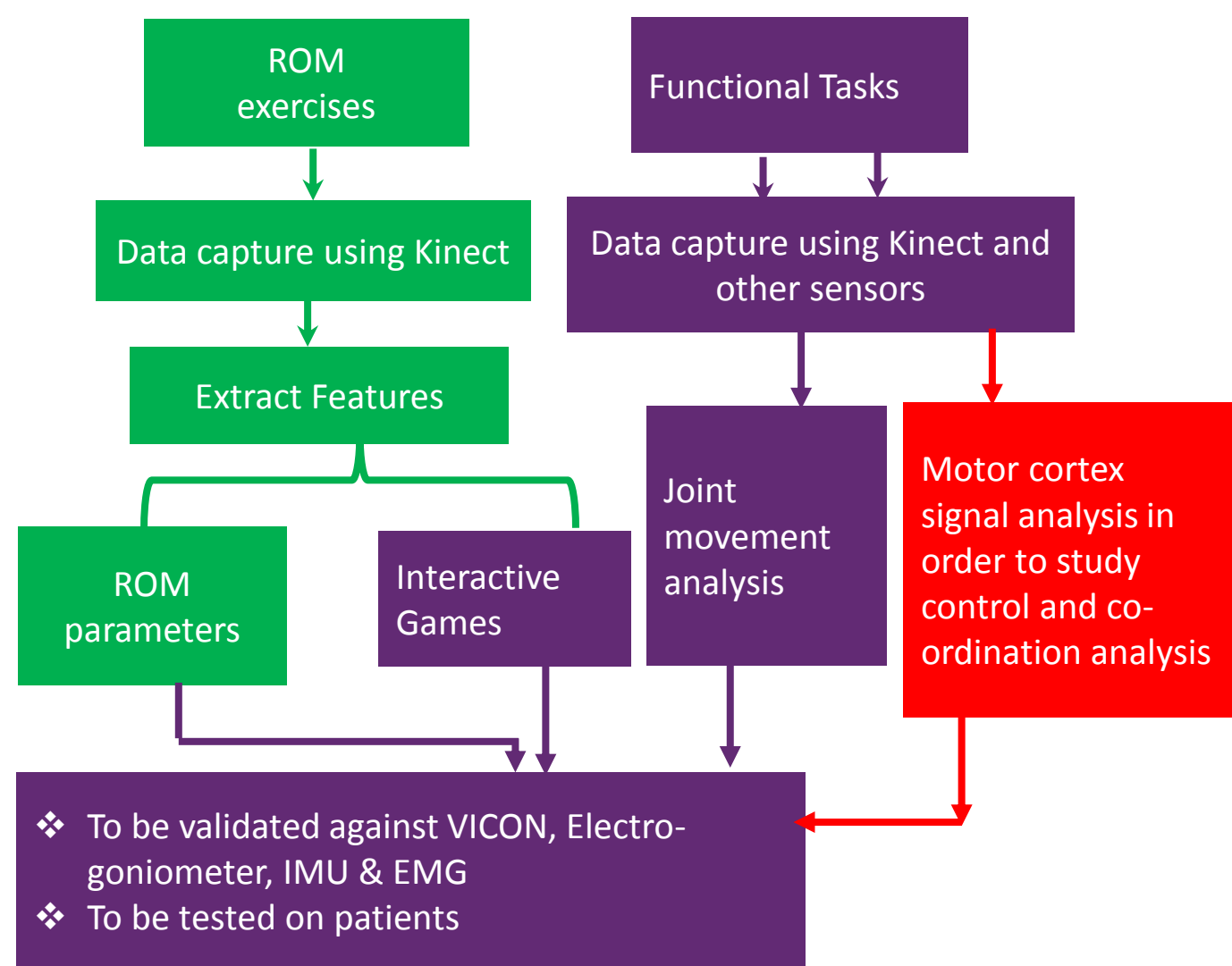
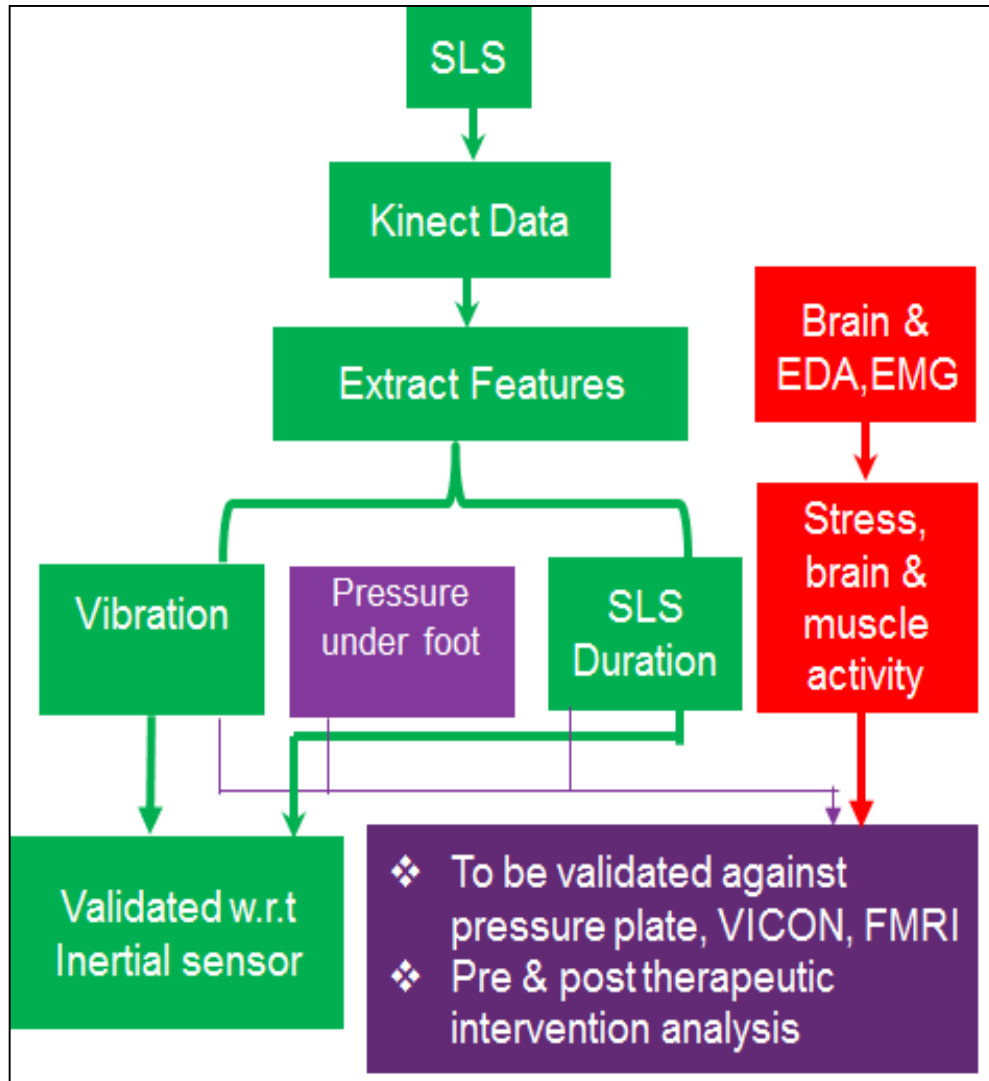
[1] Chapter 39 Rehabilitation Nursing

Our Approach for Tele-Rehabilitation – Solution Architecture

TCS RehabBox which will be used for **balance, gait and joint range of motion** analysis using Kinect sensor at home

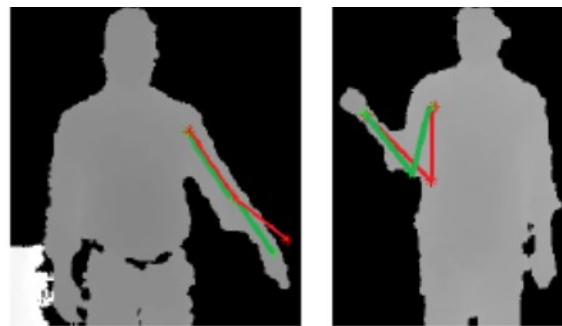
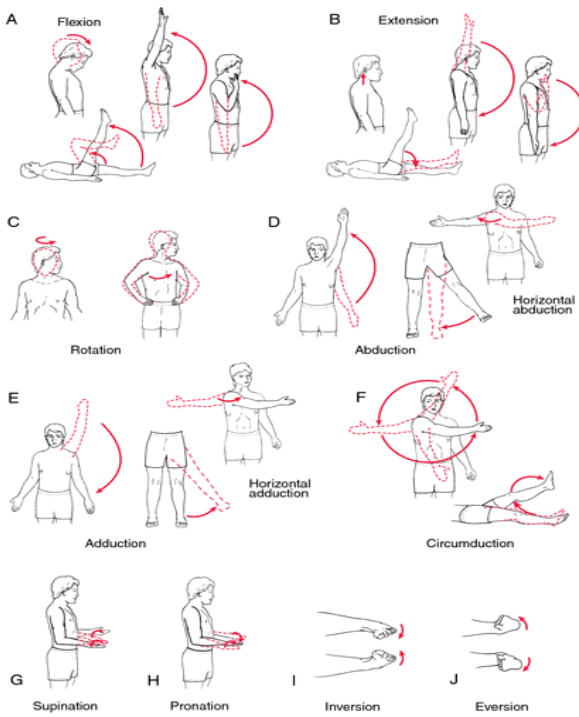


Functional Therapy Blocks – Single Limb Stance (SLS), Range of Motion (ROM)

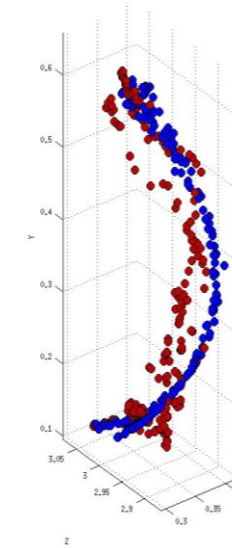
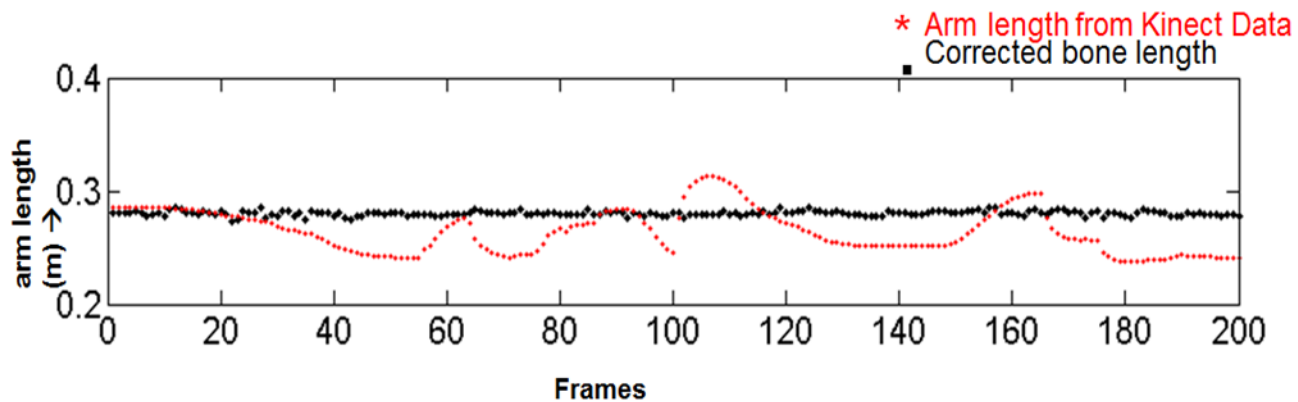


Range of Motion – Results

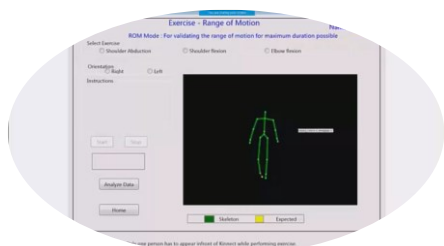
Range of motion (**ROM**) exercises like Shoulder Flexion, Shoulder Abduction, Elbow Flexion



Noise removal in Kinect Skeleton Data Using Kalman Filter



Trajectory of arm during Shoulder Flexion



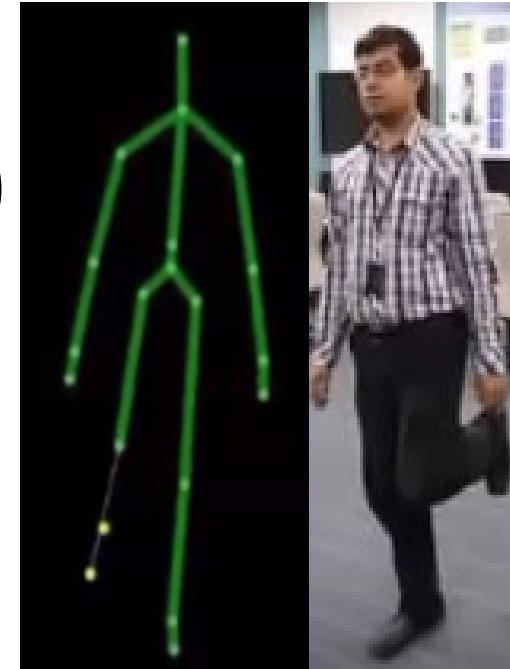
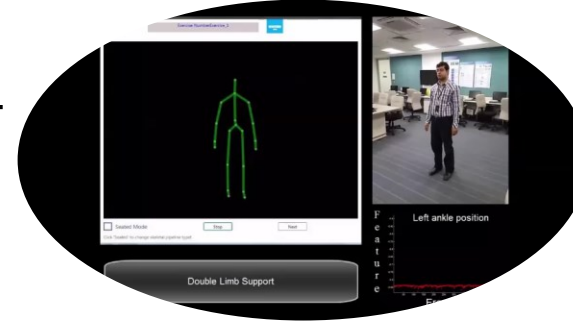
"Accurate Upper Body Rehabilitation System Using Kinect." EMBC 2016

"Improvement In Kinect Based Measurement Using Kalman Filter For Rehabilitation" ICASSP 2017, Communicated

Single Limb Stance (SLS) – Results

Stroke Patients Trials in AMRI Hospital, Kolkata, India

- **11 subjects (5 chronic stroke-survivors)**
 - ✓ 3 females, mean age 64.4 ± 8.2 yrs
 - ✓ able to stand/walk unaided.
- **History of fall was present in 80% stroke and 16.6% control subjects.**



Results

- **SLS duration was significantly low in Stroke vs Control**
 - ✓ $SLS=9.5 \pm 14.5$ second vs 55.7 ± 13.6 second, $p=0.005$
- **Both SLS duration and Vibration Index are significantly different in patients with fall vs no-fall history**
 - ✓ $SLS=6.7 \pm 9.8$ second vs 59.9 ± 13.8 second, $p=0.001$
 - ✓ $VI=0.25 \pm 0.16$ vs 0.68 ± 0.34 , $p=0.001$
- **Validation ongoing with Fall Risk Assessment Questionnaire for 400+ patients**



Summary

Stakeholder Benefits

- Reduced claims & better risk management
- Granular underwriting & Informed pricing

Insurance



- Reduced infrastructure
- Effective preventive programs/plans
- Capacity Augmentation

Hospital



- Optimized healthcare costs
- Improved lifestyle
- Screening test as an Aiding tool

Patient



- Focus on disease prevention with early intervention policies
- Affordable Screening and Therapy for masses

Govt.



- Early stage treatment
- Continual Patient Tracking
- Increase Specialist Doctor Capacity

Doctor



Achievements so far



IP

- **Papers**
 - 20+ in major conferences (ICASSP, EMBC, MobiHoc, Sensys, ICC, BSN, World Stroke Congress, INREM, ..)
- **Patents**
 - 15+ patents filed
- **Collaborations**
 - Indian Statistical Institute, Kolkata, India
 - Indian Institute of Technology, Gandhinagar, India
 - Fortis Hospital, Kolkata, India
 - AMRI Hospital, Kolkata, India



Awards

- **Awards**
 - Wearable Tech Award, 2016
 - Aegis Graham Bell Award, 2015
 - CSI Young Innovator Award, 2015
 - Best Demo Award at Sensys 2014
 - Hall of Fame, TCS Innovista
 - Finalist in Tata Innovista



Thank You

arpan.pal@tcs.com

Team

Aniruddha Sinha
Parijat Deshpande
Anirban Duttachaudhuri
Rohan Banerjee
Shreyoshi Dutta
Ramu Vempada
Deepan Das
Shahnawaz Alam
Debatri Chatterjee
Kingshuk Chakravarty
Brojeswar Bhowmick
Sanjana Sinha
Avik Ghose
Nasim Ahmed
Aiswharya Visvanathan
Arijit Sinharay

Doctor Consultants

Dr. KM Mandana
Dr. Abhijit Das