Connected Health

AI-Based Sensing for Physical and Mental Well-Being

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TATA CONSULTANCY SERVICES

IN BRIEF

Artificial Intelligence (AI), sensors, and analytics have advanced significantly and can non-intrusively, cost-effectively, and scalably screen and monitor physical and mental health. Health research is therefore focusing on wearable technologies for screening, monitoring, and care.

TCS' proprietary machine learning- and deep learning-based *marker discovery platform* (MDP), delivers unified offerings for clinical practice. TCS' MDP performs better than many existing state-of-the-art technologies.

Future research at TCS will build computational and electrical network simulations of the brain and heart. The models will guide solution development for clinical practice.

The World Health Organization (WHO) defines health as "a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity," and mental health as "a state of well-being in which every individual realizes his or her own potential, can cope with the normal stresses of life, can work productively and fruitfully, and is able to make a contribution to his or her community." Nothing can be truer in today's world, where the focus of healthcare is shifting from disease identification and therapy to holistic well-being, remaining productive, and realizing one's potential.

AI, sensor, and analytics technologies have been advancing significantly, and are now at a juncture where they can identify, in non-intrusive and cost-effective ways, the indicators of brain-mind health and physical well-being. The patterns identified by such technologies track the signs of early-stage developmental and brain disorders, mental illnesses, and degenerative neurological diseases, helping doctors and patients better predict, monitor, and track these conditions ubiquitously at a considerably lower cost than before—revolutionizing the way in which screening and rehabilitation can be conducted.

Fact File

TCS Research: Connected Health

Outcomes: Monitoring Neurological Patients, Early detection of Cardiac Diseases, Physiological Marker Discovery Platform, Won The PhysioNet Challenge 2017

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Academic Partners: IIT Kharagpur, IIT Madras, Sree Chitra Tirunal Institute for Medical Sciences and Technology

Techniques used: Embedded Signal Processing, Machine Learning & AI

Industries benefited: Hospitals, Pharma, MedTech, Medical Device

Patents: 25 filed, 8 granted

Papers: 30+ papers in IEEE, ACM Conferences and Journals

Wearable technologies for early screening, 24x7 monitoring, and swift post-event intervention and care in health-related conditions are the growing focus of health research and innovation, in the attempt to make healthcare holistic, scalable, and affordable.

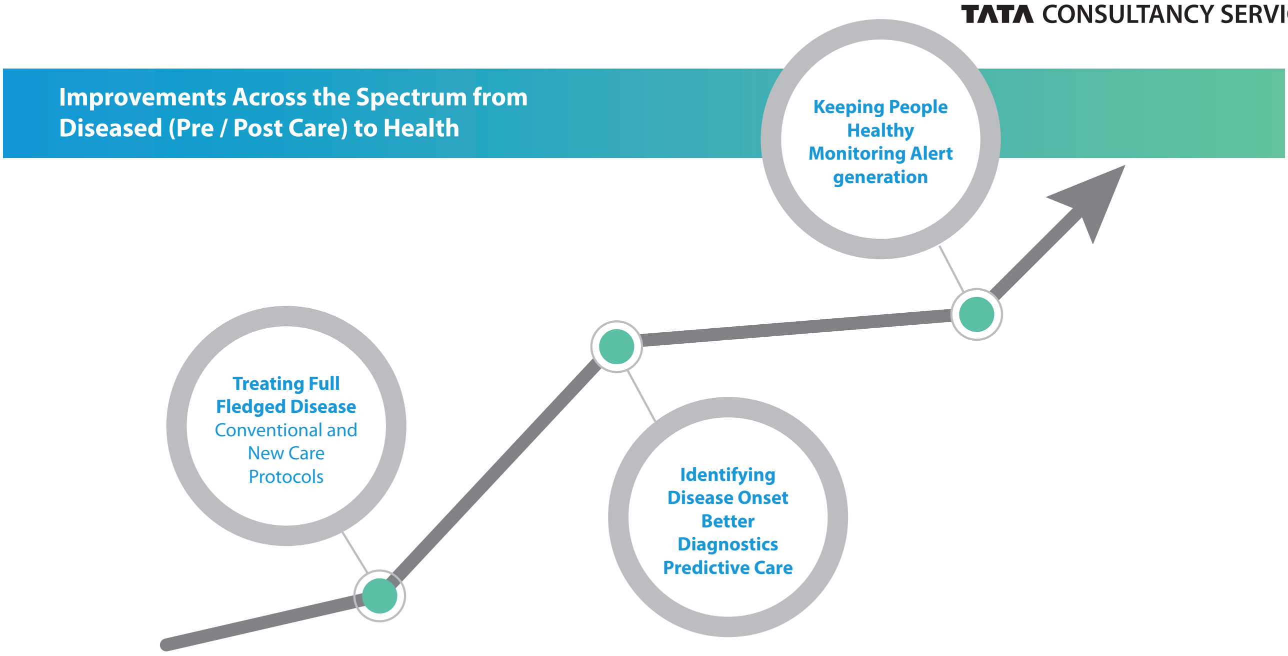
In the future that we envision, the possibilities are mind-boggling. Patients with a smartphone, a smart watch, and a few more compact, lightweight, and portable sensors would continuously be transmitting rich health data to their doctor. They would no longer need to travel to the doctor's location unless the data showed something was amiss. This would save patients time and money. Besides, the data trends would alert the doctor early, making preventive or timely action a reality.

Data from a wearable accelerometer, for example, would immediately alert the healthcare provider of a patient's fall and consequent immobility, making rapid assistance possible.

Streaming data can be an important diagnostic tool. For instance, in fluctuating hypertension, the symptoms are transient and disappear by the time the patient reaches the doctor's clinic. Data that is streamed continuously from patient to doctor can help clear diagnosis.

Historically, however, the healthcare industry has been provider-centric. Patients must reach out to the provider for the prevention, cure, and management of disease, illness, and disability. But this reactive approach has inherent problems. First, patients often contact healthcare providers too late in the disease progression stage because, in the early stages, they are asymptomatic. Second, even when contact is made and patients move to the post-event, post-trauma, or postoperative stage, the high recurring treatment costs and need for often frequent follow-ups result in patients becoming irregular in visiting the healthcare provider or, worse still, dropping out altogether.

The need for affordable, pervasive, and ubiquitous methods for screening, monitoring, and therapy



AI, sensors, and analytics are helping predict, monitor, and track health in revolutionary, low-cost ways.

is thus becoming increasingly urgent. This constitutes the motivation for TCS' work in sensing for physical and mental well-being.

The importance of research in this space is well-recognized. TCS, which has been closely tracking the substantial work underway in the area worldwide, has taken a machine learning- and deep learning-based, platform-driven approach, using hardware, software, and services bundled together to develop unified offerings for screening, monitoring, and therapy.

Screening

In this area, our primary focus has been on eldercare, cardiac and cognitive screening. Our eldercare platform is designed to fulfill three objectives—ubiquitous analytics, energy-friendly continuous monitoring, and algorithm development for stability and fall propensity analysis.

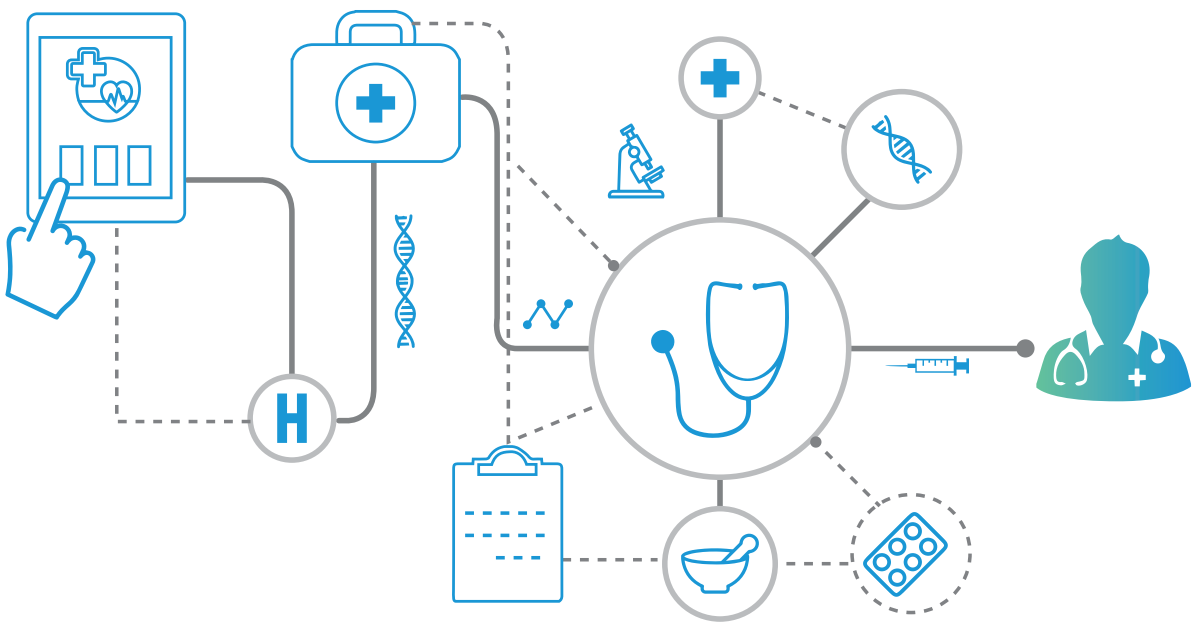
In cardiac screening, we are working on pulse signal techniques—photoplethysmogram (PPG) and phonocardiogram (PCG)-based early cardiac markers—for coronary artery disease (CAD), arterial stenosis, and related diseases. We have developed a non-invasive screening system—fingertip PPG—to identify CAD patients. We have also developed novel, low-cost, non-invasive screening for early detection of CAD patients, which uses a fusion of PCG and PPG signals. From noisy recordings, we have analyzed single-lead short-duration ECG signals, successfully classifying the heart rhythms of the normal population, and of patients of atrial fibrillation and other cardiac conditions. We have carried out automatic classification of normal and abnormal heart sounds, using a robust algorithm unaffected by signal quality and patient demography. We are also researching continuous monitoring and correlations between the activity and physiology of cardiac patients vis-à-vis normal populations and automatic selection of healthy and diseased population for clinical trials based on demography matching.

In cognitive screening, we are exploring how virtual reality- (VR-), augmented reality- (AR-), and mixed reality-based games can help screen for early onset of cognitive impairments. This should lead to breakthroughs in interventions that delay the progression of cognitive impairments which culminate in dementia.

Monitoring

Monitoring medication response and disease progression will enable better patient management. It will also aid relapse and cure prediction. We have been enhancing TCS' proprietary Connected Clinical Trial (CCT) platform to monitor Parkinson's disease (PD) patients at home, using non-intrusive digital sensing technologies—wearables, depth cameras, and smartphones—to track bradykinesia, akinesia, freezing, tremor, and abnormalities in speech, mood, and cognition resulting from medication and its side effects. Today, clinicians do not have this data and, hence, treat patients based on their verbal feedback and evaluations done intermittently during patient visits to the clinic. The data collected from these home-based monitoring devices should therefore prove not only immensely useful for clinicians to take early decisions regarding dosage adjustments and medication changes but also provide the pharma industry with detailed information on drug pharmacodynamics.

Eye movement analysis finds tremendous use in medical assessment and screening, rehabilitation, and human-machine interaction. Infrared sensor-based eye trackers are becoming popular but are expensive and need repeated calibration. Moreover, despite multiple calibrations, various types of data noise persist resulting in inaccurate gaze tracking. We have a protocol for one-time calibration that works well, uses noise-removing signal processing, and can be used on subjects for long durations.



TCS' AI-based algorithms "discover" disease patterns from raw sensor data.

Therapy

Our digital therapeutic solutions cover post-operative and post-event care. We have an offering for stroke patients, which tracks their exercise compliance through a Microsoft Kinect™-based device. This runs on algorithms we have developed to measure how a patient performs range-of-motion exercises against a clinically approved template.

Postural instability is a prominent symptom of stroke, dementia, PD, myopathy, and other physiological disorders, and a major precursor of fall risk. We have developed an affordable AR-based system for real-time quantification of postural instability to be used in tele-rehabilitation and personalized healthcare applications. Conventional stability scoring techniques require the presence of a physiotherapist, and are time-consuming and expensive. However, our system overcomes these difficulties, integrating a low-cost Microsoft Kinect™ device with an AR-based environment running a fuzzy stability scorer algorithm.

TCS' AI-based MDP

Patients' physiological data captured by various sensors requires noise cleaning, feature extraction, and machine learning algorithms to extract medically meaningful information for screening, monitoring, and therapy.

The success of any machine learning-based application depends largely on finding an optimum set of discriminative features. The discriminative features correspond to biomarkers of severity for a given disease. Determining the feature set is a challenging task, manual in nature, and thus, time-consuming, requiring in-depth domain knowledge.

TCS has therefore developed a proprietary MDP, which, using machine learning and deep learning algorithms, automates marker generation from physiological signals and features recommendations from diverse sensor data, thereby providing a unique representation of input sensor signals in the feature space

Parkinson's patient: *Towards better treatment using sensor based data* for performing a predefined classification task.

The MDP takes raw sensor signals and user-provided annotations as input and, based on classical machine learning and deep learning approaches (i.e., with no domain information), generates a generic feature set encompassing statistical features, signal processing, and information theory-based features, and makes quick recommendations that capture the inherent properties of the sensor data well. The MDP also allows users to add their own feature sets (mainly domain-specific features) to the MDP's native feature set.

For classification, users select the required application-specific performance metrics—F_1 score, classification accuracy, sensitivity, and specificity—from a metrics universe. The MDP's suite of inbuilt algorithms then recommends an optimum feature set from the composite feature set for discovering the significant markers from the physiological data corresponding to a specific disease category.

Apart from feature recommendation, the MDP, running a list of well-known, tested and supervised learning algorithms, can also report the benchmark accuracy that can be obtained by using the recommended features.

To test for domain independence, TCS has evaluated the MDP on several openly available sensor databases from a range of unrelated domains—including biomedical, machine vibration, and transport—and found it to be effective. In fact, the MDP's performance, in most cases, has been comparable or better than existing state-of-the-art techniques.

Future directions

The world is moving toward biomodeling techniques for screening and therapy. Computational models of biological systems will be essential in enhancing prediction accuracy in biomedical sensor-based systems. Therefore, at TCS, we plan to develop computational models of the two most important and complex organs of the human anatomy—the brain and the heart.

Our aim is to develop a connectome model—a network-based brain simulation platform – that establishes structural-functional relationships in the resting and the active brain. We expect to use imaging data to analyze the stability and controllability of the neural networks, which will have application in epilepsy and stroke management and recovery.

On similar lines, we hope to build an alternating current (AC) model in which the heart is simulated as the AC source and the circulatory system, as a network of current elements. The model will use the circuit equations of physics to understand cardiac functions and explore the use of non-intrusive pulse signals and heart sounds to identify arterial fibrillation, hypertension, and other complex cardiac abnormalities.

We are also studying mental well-being by leveraging multiple sensing modalities to screen mental conditions and make recommendations for appropriate interventions, using a fusion of medical knowledge and AI techniques. Such an approach may control what the American Academy of Neurology's medical journal *Neurology*, in its November 2012 issue, called India's hitherto hidden neurologic disability epidemic.

Aniruddha Sinha

Aniruddha Sinha is a Senior Scientist in TCS Research and Innovation. His research areas include Embedded Systems and Robotics. His expertise lies in analysis of multimedia content, sensor signal processing related brain signals and electrophysiological analysis. He has more than 20 years of industrial experience and published several papers in peer reviewed International IEEE and ACM conferences and journals. He has more than 30 granted patents in USA and Europe.

He has a BE Degree in Electronics and Tele-Communication Engineering from Jadavpur University, Calcutta and MTech in Electrical & Electronics Communication Engineering from IIT-Kharagpur. At present he is pursuing PhD in the area of modeling the cognitive and psychological factors in personalization of education. He is a senior IEEE member.

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