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IoT based wake-up stroke prediction - Recent trends and directions

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Abstract. Stroke is a brain attack occurs when the “sudden disturbance of blood supply” to the brain. The reasons could be either the blood supply suddenly interrupted to part of the brain or a blood vessel ruptures or blood invades the surrounding area. Wake-up stroke – stroke onset during night-time sleep, where a patient waking-up with stroke symptoms that were not present before falling asleep. Recently, stroke on awakening (i.e., stroke symptoms within 30 min of awakening) also included wake-up stroke group. Studies indicated that the percentage of wake-up stroke between 8 to 28 % of all ischemic strokes. It is difficult to treat this large group of patients, since, the exact time of stroke onset unknown. Internet of Things (IoT), an extensive set of technologies could be used as one of the solutions to predict stroke onset. This paper discusses the critical role of IoT on wake-up stroke prediction. The physiological parameters measured while sleeping, risk factors associated with stroke, embedded and wearable sensors used for sleep monitoring, and data mining techniques available for diseases prediction are discussed. Finally, the outline of our developing wake-up stroke prediction system is presented.

1. Introduction

A stroke occurs when blood supply disturbed to the brain and its parts. The source could be ruptured blood vessels, blood clot lodges in a cerebral artery, diseased carotid artery, bleeding inside or around brain tissue. The reduced blood supply to the brain results deprived of oxygen to brain cells, which lead to cell death [1]. The stroke symptoms may vary to the type of stroke (clots, bleeds, and transient ischemic attack), and amount of damage in brain tissues. The symptoms include arm weakness, speech
difficulty, face drooping, trouble walking, blurred vision, dizziness, memory loss, loss of sensation, change in stiffness in the muscles, swallowing problems, co-ordination issue \[2, 3\].

Stroke causes mortality and also significant morbidity. The victim needs to be treated within a few hours (4.5 hours) of incidence to prevent (only morbidity) permanent damage from stroke. The only FDA approved nonsurgical reperfusion therapy is a tissue-plasminogen activator. Mostly, about 70% of stroke occurs in the daytime or when the victim in awakens state. Approximately, 8 to 28% of ischemic stroke happens while the victim on night-time sleep. That being the case, stroke symptom onset time, or when the victim was last known to be normal are unknown. This phenomenon refers to wake-up stroke. The symptoms of wake-up stroke only known upon awakening \[3, 4\]. Hence, the victims affected by wake-up stroke are left out from the FDA approved tissue-plasminogen activator therapy due to missing stroke onset time.

Recent development in imaging technique used to suggest whether wake-up stroke initiated within 4.5 hours. An example, the wake-up project [www.wakeup-stroke.eu] has developed an approach that uses brain MRI and identifies the stroke lesion age. However, this technique not for regular or daily use. Also, MRI imaging techniques are expensive and need expert doctors. However, it is vital to have a technology to detect and promptly alert the stroke onset automatically. Internet of Things (IoT), an extensive set of techniques could be used as one of the solutions to predict stroke onset. The following sections discuss stroke in India, risk factors associated with stroke, the physiological parameters measured while sleeping, embedded and wearable sensors used for sleep monitoring, and data mining techniques available for diseases prediction.

2. Stroke in India

Stroke in India is increasing with its thriving population and even more than Western countries. The Indian population is continually evolving; it had grown massively from 1,028 million in 2001 to 1,210 million in 2011 [5]. The projected India population as follows: 1,319 million in 2020, 1,469 million in 2030, 1,619 million by 2040. It is expected to become the most peopled country by 2040 by beating China 1,525 million in 2040. For India, it will take only 22 years from now on to become the most peopled country in the world. Worldwide, stroke is the second leading causes of death after the coronary attack. In India, the percentage of death due to stroke and the ischemic attack was 13% and 14%, respectively.

In India; stroke is one of the leading causes of death [6]. According to stroke study [7] on the community of a metropolitan part of Kolkata from 2003 to 2004, it was found to be 4.72 per 1000 persons (Male: 4.96/1000; Female 4.44/1000). Both world and stroke population are increasing and ageing. In Asia, the developed countries such as Korea, urban China, and Japan, the stroke mortality has been declining with increased resources. However, in India with limited resources, the mortality rate is rising [8-11]. Awareness of the stroke warning symptoms among India public is limited. Based on studies [12, 13], the improved socioeconomic status and higher education increase the awareness of the stroke among countryside and city people in India. As mentioned earlier, the stroke victims need to be treated within 4.5 hours of stroke onset. However, a study [12] reported the average arrival time of stroke patients to the hospital was 35 ± 6 hours. In India, there are numerous independent variables or factors documented concerning stroke including lack of education, socioeconomic status, lack of expert doctors, lack of equipped hospitals, lack of transportation, lack of awareness and lack of therapeutic time window. All these factors increase the mortality rate in India. A comparative hospital-based study reported that almost 37% of stroke was a wake-up stroke in India. They have claimed that diabetes mellitus began as the leading risk factor for wake-up stroke. Also, reported that recovery after stroke was appreciated more in non-wake-up stroke as compared with wake-up.

3. Risk Factors for Stroke

The risk factors are classified as modifiable and non-modifiable. Various studies reported these risk factors. The changeable risk factors are including tobacco use, diabetes, hypertension,
hypcholesterolemia, alcohol intake, anticoagulants, atrial fibrillation, low haemoglobin, and obesity [14 - 16]. The non-changeable risk factors are age and low-birth weight.

4. Sleep and physiological parameters
Sleep plays a critical role in maintaining good health, and we spent about 1/3 of our life in sleeping. The physiological parameters could be measured during sleep are brain waves, eye movement pattern, cardiovascular measurements, face muscle activity pattern, respiration, blood pressure, skin moisture level and temperature. These parameters are affected when there is an onset of wake-up stroke. Stroke onset caused by the disturbed cerebral blood flow (the blood supply to the brain in a given period). Therefore, electrical activity changes would occur in the brain neurons due to the variation in the blood flow. The electrical activity measured by electroencephalogram (EEG) techniques. A recent study [17] highlighted the marked changes in EEG power in stroke patients. It was reported as increased delta (1-4 Hz) power accompanied by a decreased power in both alpha (8-14 Hz) and Beta (14-30 Hz). These changes are directly linked to ischemic injury [18-21]. In a study, the interpretation of EEG frequencies with the changes in blood flow was reported [22, 23]. It was reported the absences of alpha frequencies when the blood flow declines to 25-35 ml/100g/min range when the blood flow declines further to 17-18ml/100g/min the appearance of theta frequencies occur. The blood flow range between 17-18ml/100g/min is critical, where the neurons switch to drop their transmembrane gradients and to lead to brain cell death. The delta frequencies appear when the blood flow range between 12-18 ml/100 g/min. The EEG activity becomes hushed, and cellular impairment becomes permanent when the blood flows at 10-12ml/100g/min and below. Hence, by measuring EEG continuously during sleeping, it is possible to locate the age of wake-up stroke [24, 25].

The cardiovascular activity is linked to cerebral blood flow. Electrocardiogram (ECG) is the process which is used to record the electrical activity of heart muscles. Studies confirmed the abnormalities in the ECG waveform associated with stroke [26]. The ECG waveform abnormalities include ST-segment changes, prolongation in QT, inverted T wave. A study reported the QT prolongation, T wave inversion followed by ST segment changes for stroke patients considered [27]. Similarly, other physiological parameters affected at a stroke. However, how to measure these physiological signals while someone at sleep without disturbing their sleep pattern. The challenges are enormous. Therefore, sleep monitoring is essential to find the age of stroke (i.e., stroke onset time), also could be used to predict the stroke before it occurs.

5. IoT based Devices for sleep monitoring
In wearable electronics, one of the most happening research application is health monitoring. Smart health monitoring is the integration of smart computing and remote health monitoring with IoT (Internet of Things). The IoT as a network of wearable smart devices, which connect with each other to measure the parameters, interpret the results and make the emergency alert to notify the medical personnel. It can be used for remote monitoring and emergency notification systems. Nowadays numerous wearable devices have been developed to measure physiological parameters during sleep. The wearable devices for sleep monitoring including SenseWear, SleePic system, Heally recording system, M1, Zeo, iBrain, etc. The wearable devices available in the market has its sensitivity and specificity issues. Most of the devices are in the developmental stage. Therefore, there needs to be validation before engaging them for sleep monitoring. An elastic band type wearable device (Zeo) can measure brainwave, muscle activity details, and eye movement details. It consists of a lightweight EEG brainwave monitor. The Zeo device has 75% agreement with polysomnography (the gold standard in sleep measurements). In addition to sleep monitoring through physiological signals, body movement based sleep monitoring wearable devices also available. This includes sleep tracker, wake mate, beddit, Fibit, Lark, etc. For example, the Fibit wearable device can measure sleep and wake metrics. However, there aren’t any validation studies [2].
6. Stroke Prediction
These wearable sensors are used as sleep trackers where we could measure several physiological parameters related to stroke. Each physiological parameter includes many variables. For example, the EEG as a parameter may consist of variables like frequency bands (alpha, beta, theta, delta, gamma), and its power, frequency band ratio, relative power ratio. The ECG as a parameter may include variables like beat-to-beat interval, QT interval, P interval, ST elevation or depression, T wave inversion, PR interval, U waves. Similarly, muscle activity, i.e., Electromyography may include variables like mean power, median frequency, amplitude, RMS. Concerning eye movement, i.e., Electrooculography (EOG) may consist of variables like horizontal and vertical movement, blink rate, muscle activity around the eyes. Similarly, PPG measurement, breath measurement, leg movement measurement include lots of variables [2, 28]. Therefore, there is going to be a Big data concerning sleep monitoring alone. With these big data, there is a need for accurate analysis of this big data. This precise analysis would assist to early detection of diseases, i.e., prediction of conditions, healthcare and services. The diseases prediction viewed as a critical topic. Since, the incorrect decisions could cause delays in medical care or permanent illness to stroke patients, or even loss of life. Not many prediction models were proposed for stroke detection. A recent work developed a prediction model for stroke by considering patient demographic [29]. The work analysed the demographic data using various data mining techniques including Naïve bays, neural network, and decision tree. The conclusion made was that the decision tree prediction accuracy better than other two models. However, the neural network was better than other two models about the safety of life. To predict the risk level of transient ischemic attack the system was designed based one ontology and Bayesian belief networks [30]. Another study [31] considered the climatic factors and developed a stroke prediction model with the help of multiple regression analysis. Few more studies were reported the stroke prediction models by considering patients electronic health record. The following models reviewed the patient's electronic health record: Cox proportional model [32], integrated machine learning [33], Bayesian list machine model [34], and multivariate Cox model. However, with authors’ knowledge, there isn’t any study for predicting wake-up stroke through above models.

7. Our project scope
Our stroke project objective is to real-time detection and generation of alarms for wake-up stroke through IoT. Our project could allow the appropriate arrangement of medical assistance. Our system includes intelligence technology which is controlled by hyper-connected self-machine learning engine. The system would have big data built with physiological data measured at sleep, body movement data, modifiable and non-modifiable risk factors, and also electronic health record. The sleep parameters and body movement data are measured through wearable sensors. Our system intelligence includes multi-model learning including support vector machine (SVM), Random forest algorithm, convolutional neural network (CNN) algorithm, long short-term memory algorithm, deep learning algorithm and model generator. If our developing system predicts stroke symptom above 90%, it will alarm the family, people around the victim, medical doctors, and the victim. The following figure (Fig. 1) giving overall outlook our developing system. The possible physiological parameters and its variables measured during sleep are given (Fig. 2).
8. Conclusion/Summary
Wake-up stroke – stroke onset during night-time sleep, where a patient waking-up with stroke symptoms that were not present before falling asleep. This paper discussed the role of IoT on wake-up stroke prediction, the physiological parameters and variables while sleeping, available wearable sensors. Also, discussed the diseases prediction algorithm in this research field. Finally, briefly explained our developing system for stroke prediction.
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9. References

[1] Hong K S, Bang O Y, Kang D W, Yu K H, Bae HJ, Lee J S, Heo J H, Kwon S U, Oh C W, Lee B C and Kim J S 2013 Stroke statistics in Korea: part I. Epidemiology and risk factors: a report from the Korean stroke society and clinical research center for stroke, Journal of Stroke. 15(1), 2.

[2] Subramaniyam M, Hong S H, Yu J and Park S J 2017 Wake-Up Stroke Prediction through IoT and Its Possibilities, In Platform Technology and Service (PlatCon), 2017 International Conference IEEE. 1-5.

[3] The Atlas of Heart Disease and Stroke. WHO, 2016.

[4] Rimmele D L and Thomalla G 2014 Wake-up stroke: clinical characteristics, imaging findings, and treatment option—an update, Frontiers in neurology. 5, 35.

[5] Census of India, www.censusindia.gov.in Accessed 20/02/2018

[6] Joshi R, Cardona M, Iyengar S, Sukumara R, Raju C R, Raju KR, et al., 2006 Chronic diseases now a leading cause of death in rural India — mortality data from the Andhra Pradesh Rural Health Initiative, Int J Epidemiol., 35, 1522.

[7] Das S K, Banerjee T K, Biswas A, Roy T, Raut D K, Mukherjee C S, et al., 2007 A prospective community-based study of stroke in Kolkata, India. Stroke. 38, 906-10.

[8] Suwanwela, N C and Poungvarin N 2016 Stroke burden and stroke care system in Asia, Neurology India. 64(7), 46.

[9] Kim J S 2014 Stroke in Asia: A global disaster. Int J Stroke, 9, 856.

[10] Mehdiratta M M, Khan M, Mehdiratta P and Wasay M 2014 Stroke in Asia: Geographical variations and temporal trends, J Neurol Neurosurg Psychiatry 85, 1308-12.

[11] Krishnamurthi R V, Feigin V L, Forouzanfar M H, Mensah G A, Connor M, Bennett D A, et al., 2013 Global burden of diseases, injuries, risk factors study 2010 (GBD 2010); GBD Stroke Experts Group. Global and regional burden of first-ever ischemic and hemorrhagic stroke during 1990–2010: Findings from the Global Burden of Disease Study 2010 Lancet Glob Health 1, e259–81.

[12] Das K, Mandal G P, Dutta A K, Mukherjee B and Mukherjee B B 2007 Awareness of warning symptoms and risk factors of stroke in the general population and in survivors of stroke. J Clin Neurosci., 14, 12-6.

[13] Pandian J D, Jaison A, Deepak S S, Kalra G, Shams S, Lincoln DJ, et al., 2005 Public awareness of warning symptoms, risk factors, and treatment of stroke in northwest India. Stroke, 36, 644-8.

[14] Kalita J, Goyal G, Kumar P and Misra U K 2014 Intracerebral haemorrhage in young from a tertiary neurological centre in North India, J Neurol Sci., 336, 42-7.

[15] Singla S and Singla R 2016 Stroke in India: Bio-socioeconomic determinants, Journal of Social Health and Diabetes. 4(2), 71.

[16] Siegler J E, Boehme A K, Kumar A D, et al., 2013 Identification of modifiable and nonmodifiable risk factors for neurologic deterioration after acute ischemic stroke. J Stroke Cerebrovasc Dis., 22, e207-13.

[17] Fanciullacci C, Bertolucci F, Lamola G, Panarese A, et al., 2017 Delta power is higher and more symmetrical in Ischemic Stroke patients with cortical involvement, Frontiers in human neuroscience, 11, 385.

[18] Faught E, 1993, Current role of electroencephalography in cerebral ischemia, Stroke. 24, 609–613.

[19] Lu X, Williams A J and Tortella F C 2001 Quantitative electroencephalography spectral analysis and topographic mapping in a rat model of middle cerebral artery occlusion, Neuropathol. Appl. Neurobiol., 27, 481-495.
[20] Foreman B and Claassen J 2012 Quantitative EEG for the detection of brain ischemia, *Crit. Care* 16, 216.

[21] Wu J, Srinivasan R., Quinlan E B, Solodkin A, Small S L and Cramer S C 2016 Utility of EEG measures of brain function in patients with acute stroke, *J. Neurophysiol.*, 115, 2399–2405.

[22] Foreman B and Claassen J 2012 Quantitative EEG for the detection of brain ischemia, *Critical care*. 16(2), 1-9.

[23] Sharbrough F W, Messick J M, and Sundt T M 1973 Correlation of continuous electroencephalograms with cerebral blood flow measurements during carotid endarterectomy, *Stroke*. 4(4), 674-683.

[24] Hossmann K A 1994 Viability thresholds and the penumbra of focal ischemia, *Ann Neurol.*, 36(4), 557-565.

[25] Jordan K G 2004 Emergency EEG and continuous EEG monitoring in acute ischemic stroke, *J Clin Neurophysiol.* 21(5), 341-352.

[26] Togha M, Sharifpour A, Ashraf H, Moghadam M and Sahraian M A 2013 Electrocardiographic abnormalities in acute cerebrovascular events in patients with/without cardiovascular disease, *Annals of Indian Academy of Neurology*. 16(1), 66-71.

[27] Goldstein D S 1979 The electrocardiogram in stroke: relationship to pathophysiological type and comparison with prior tracings, *Stroke*. 10(3), 253-259.

[28] Park S J, Subramaniyam M, Moon M K, Jeon B B, Lee E J, Han S H and Woo C S 2014 Sleep Quality and Skin-Lightening Effects of White Mother Chrysanthemum Aroma, *Industrial Applications of Affective Engineering*, Springer International Publishing, Switzerland.

[29] Kansadub T, Thammaboosadee S, Kiattisin S and Jalayondeja C 2015 Stroke risk prediction model based on demographic data, *Proc of the 8th Biomedical Engineering International Conference, IEEE*. 1-3.

[30] Mcheick H, Nasser H, Dbouk M and Nasser A 2016 Stroke prediction context-award health care system, *First international conference on Connected Health: Applications, Systems and Engineering Technologies, IEEE*, 30-35.

[31] Yang J, Ji L, Wang Q and Lu X 2016 The prediction model of stroke on climate factors by multiple regression. *Information technology, networking, electronic and automation control conference, IEEE*, 587-591.

[32] Cao K Y, Lin C C, Chiu H K, Hu J, and Lee H 2010 An integrated machine learning approach to stroke prediction. *Proc of the 16th ACM SIGKDD international conference on Knowledge discovery and data mining, ACM, Washington, DC, USA*, 2010.

[33] Letham, Rudin C, McCormick T H and Madigan D 2015 An interpretable stroke prediction model using rules and Bayesian analysis. *Annals of Applied Statistic*. 9(3), 1350-1371.

[34] Chien K L, Su T C, Hsu H C, Chang W T, Chen P C, Sung F C, Chen M F and Lee Y T 2010 Constructing the Prediction Model for the Risk of Stroke in a Chinese Population Report From a Cohort Study in Taiwan, *Stroke*. 41(9), 1858-1864.