# iSyNCC: An Intelligent System for Patient Monitoring & Clinical Decision Support in Neuro-Critical-Care

Mengling Feng, *Member, IEEE* , Zhuo Zhang, Feng Zhang, Yu Ge, Liang Yu Loy, Kuralmani Vellaisamy, Wenyuan Guo, Pei Loon Chin, Nicolas Kon Kam King, Beng Ti Ang, Cuntai Guan

***Abstract* — Close monitoring and timely treatment are extremely crucial in Neuro Intensive/Critical Care Units (NICUs) to prevent patients from secondary brain damages. However, the current clinical practice is labor-intensive, prone to human errors and ineffective. To address this, we developed an integrated and intelligent system, namely iSyNCC, to enhance the effectiveness of patient monitoring and clinical decision makings in NICUs. The requirements of the system were investigated through interviews and discussions with neurosurgeons, neuroclinicians and nurses. Based on the summarized requirements, a modular 2-tier system is developed. iSyNCC integrates and stores crucial patient information ranging from demographic details, clinical & treatment records to continuous physiological monitoring data. iSyNCC enables remote and centralized patient monitoring and provides computational intelligence to facilitate clinical decision makings.**

## I. Introduction

Patients in Neuro Intensive/Critical Care Units (NICUs) often suffer from certain levels of brain damage. The major challenge in patient monitoring and treatment in NICUs is that the primary brain damage is often compounded by secondary damages that occur during the patient's stay in NICUs [1]. The secondary brain damage, formally known as "the secondary insult", can be caused by intracranial hypertension or insufficient oxygen and nutrition supple to the brain. Many studies [2-4] have demonstrated that secondary insults have significant effects on the mortality and recovery rates of patients. Secondary insults can potentially be reduced and prevented with the help of continuous patient monitoring and timely treatments [5], [6].

In the current NICU practice, patient monitoring & treatment mainly rely on manual inspections and experience-based judgments from clinicians and nurses. The current approach is labor-intensive, prone to human errors and ineffective. Moreover, it introduces huge amount of pressure on clinicians and nurses. To address this, we developed an integrated and intelligent system to enhance the effectiveness of patient monitoring and clinical decision makings in NICUs. The system is named as iSyNCC --- an **i**ntelligent **S**ystem for **N**euro-**C**ritical-**C**are.

iSyNCC provides an integrated platform that gathers a wide spectrum of patient information, which includes demographic data, clinical records, continuous treatment records and multi-modal physiological monitoring data. Based on the integrated data, iSyNCC analyzes and forecasts patients' changing physiological status and generates alerts for impending changes of the status. In addition, iSyNCC also predicts patients' recovery outcome, which serves as a reference for clinical decision makings.

## II. System Requirement Analysis

After interviews and discussions with neurosurgeons, neuroclinicians and nurses in NICU, the key requirements for our intelligent system are summarized as follows.

- **Data Acquisition**. In NICU, multiple physiological readings of patients are continuously measured with various monitoring devices. A data acquisition unit is required to collect the physiological reading from all monitoring devices.
- **Data Storage**. A database is required to store various patient information, which includes demographic details, clinical data, physiological monitoring data and records of continuous treatment that patients have received during their stay in NICU. Since patients' data come from multiple sources, collected data must be integrated and synchronized.
- **Data Transmission**. A data transmission network must be employed to transfer collected monitoring data to the database server. The transmission network must ensure collected data is transmitted reliably without any loss or distortion. The transmission network should also avoid any interference with other transmission network in NICU.
- **User Interface**. User interface of the system should allow clinicians and nurses to interact with the system and perform the following actions: 1) real-time observation of patient monitoring data, 2) review of historical monitoring data, 3) record treatment details and clinical events, and, most importantly, 4) visualize data-driven analytic & predictive results generated by the intelligent system.

## III. System Design & Implementation

### A. Overview of System Architecture

Figure 1 graphically illustrates the architecture of iSyNCC, the proposed system. iSyNCC follows the front-

Mengling Feng, Zhuo Zhang, Feng Zhang Yu Ge, Liang Yu Loy, Kuralmani Vellaisamy, Wenyuan Guo, Peiloon Chin and Cuntai Guan are with the Institute for Infocomm Research (I2R), Agency for Science, Technology and Research (A*STAR), Singapore.

Nicolas Kon Kam King and Christopher Beng Ti Ang are with National Neuroscience Institute (NNI), Singapore.

Corresponding author: Mengling Feng, Tel: (65) 6408 2160 Fax: (65) 6776 1378 Email: mornin@gmail.com.

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end back-end 2 tier structure. The front-end of the system consists of the "Data Acquisition" module, which ensures continuous data collections and transmission, and the "User Interface" module, which allows clinician and nurses to interact with the system. The back-end of the system is then composed with the "Database" module, for data integration and storage, and the "Computational Intelligence" module to perform data-driven analytic tasks to enhance patient monitoring and clinical decision makings. The front-end and back-end modules communicate through a local wireless network. The system is not directly connected to the internet, due to privacy and data security concerns.

iSyNCC is designed to be modular-based. This gives us the flexibilities to update, enhance, modify or change the modules of the system. This also allows the system to be scaled up and down easily by adding/removing modules.

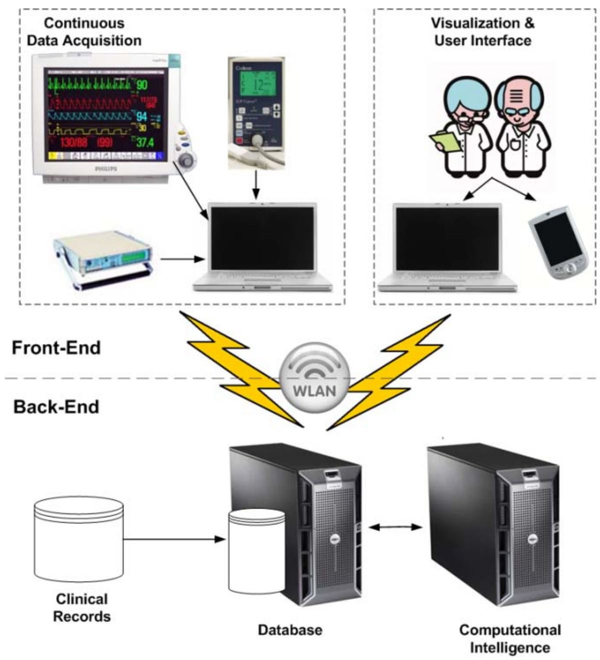


**Figure 1 Overview of system architecture of iSyNCC.**

### *B. Data Acquisition*

The main task of the "Data Acquisition" module is to continuously collect physiological monitoring data from multiple devices. In our NICU setting, patients' intracranial pressure (ICP) is monitored with the *Codman ICP monitoring system*, and brain tissue oxygen (PtiO2) and brain temperature are measured with the *Licox CMP Brain Tissue Oxygen and Temperature Monitor*. The other physiological readings are then monitored using the *Philips Intellivue* system.

The data acquisition unit will first decode all signals from various monitoring systems, and it will further synchronize the data based on their time stamps. The collected data will be transmitted to the back-end database server through the wireless transmission network.

### *C. User Interface*

The "User Interface" module communicates with the back-end database server through the local wireless network. The user interface module sends various requests and input data to the back-end database server and receives monitoring data and analytic results from the back-end server. The user interface module is to be deployed in hand-held devices of clinicians and nurses. This enables remote and centralized patient monitoring, which greatly improves the labor efficiency in NICUs. Moreover, the user interface module also allows clinicians and nurses to review historical monitoring data, to record significant medical events and to visualize analytic and decision support results generated by the system.

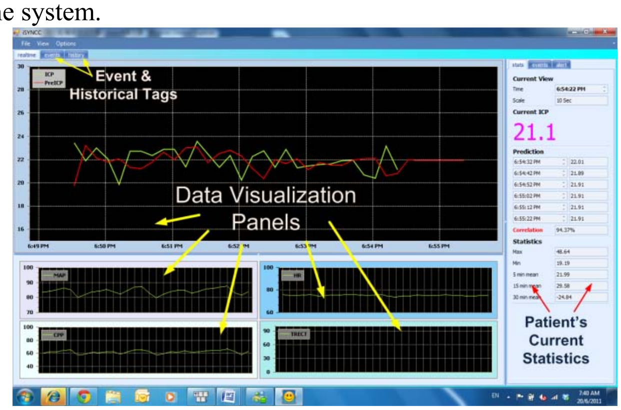


**Figure 2 Graphical user interface.**

Figure 2 shows a snapshot of the Graphical User Interface (GUI) of the system under the "real-time" view. In the real-time view, the main GUI window is split into 5 *Data Visualization Panels*. These panels allow clinicians and nurses to monitor 5 different physiological readings at the same time. Moreover, forecasted reading values are also displayed in the main visualization panel. This allows clinicians to observe the development trends of patients' physiological readings and get prepared if any dramatic changes are predicted. Besides the real-time view, users can switch to the "event" view and the "history" view. In the "event" view, users can review and edit the details of recorded events. All the recorded events coupled with their time stamp will be sent to the back-end database server for storage. In the "history" view, users can review and analyze the historical monitoring data of patients.

### *D. Transmission Network*

A local wireless transmission network is proposed to support communication between the front-end and back-end modules of the proposed system. Wireless network is chosen to avoid laying of long data cables, which is time-consuming and cost ineffective, and to enable remote and centralized patient monitoring.

In our NICU setting, a wireless network following standard *IEEE 802.11g* with 2.4GHz transmission frequency has previously been deployed for other purpose. To avoid interference with the current network, our wireless network follows *IEEE802.11n* standard and transmits in 5GHz frequency. After analyzing the layout of the NICU, three WLAN access points are to be deployed to provide full network coverage and ensure lossless data transmission. For the access points, Linksys router *WRT610N* is used; and for the mobile nodes on data acquisition and user interface devices, *Linksys WUSB600N Wireless USB Adapter* is used.

### E. Database

As shown in Figure 1, the back-end "Database" module is the centralized node of iSyNCC. Through the wireless transmission network, the database server receives continuous monitoring data from the data acquisition module and event data from the user interface module. The database server also collect patients' demographic data and clinical & treatment records from hospital's existing database. The database server integrates various types of patient data and stores it into a relational database. In particular, the database is implemented using Microsoft SQL server 2008. The integrated data is then feed to the computational intelligence module to support data-driven analytic tasks. The analytic results from the computational intelligence module will also be stored in the database server. Upon request, both collected data and analytic results will be transmitted, through the wireless network, to the user interface module for visualization and inspection.

The database server stores multiple types of patient data from various data sources. All the collected data are integrated with respect to the patients' *Admission ID*. Note that, instead of *Personal ID*, *Admission ID* is used as the primary key to link up various data. This is because one patient may be admitted to the NICU for more than once and for different reasons. Only the *Admission ID* can uniquely identify one particular NICU stay of one patient.

The various types of collected patient data can be classified into three categories [7]: 1) *one-time data*, e.g. demographic information and clinical records; 2) *continuous periodic data*, e.g. continuously recorded physiological monitoring data and forecasting data; and 3) *continuous episodic data* --- data that is continuously updated but on irregular basis, e.g. clinical treatment records, generated alters, diagnostic information. For, the continuous periodic and episodic data, time information is crucial, for, without the underlying time information, the data is meaningless. Therefore, the continuous periodic and episodic data are all coupled and synchronized with time stamps.

### F. Computational Intelligence

The "Computational Intelligence" module serves as the "brain" of the whole system. The computational intelligence module gathers patients' data from the database server. Data mining and signal processing techniques are employed to perform various data-driven predictive and analytic tasks. The computed predictive and analytic results are then used to generate alters for impending changes of patient status, to assist treatment response understanding and to guide clinical decision makings. The computational intelligence module is also implemented in a modular manner. As shown in Figure 3, the computational intelligence module can be broken down into multiple sub-modules, and the major ones are "Artifact Removal", "Short-term Monitoring Data Forecasting" and "Recovery Outcome Prediction" modules.

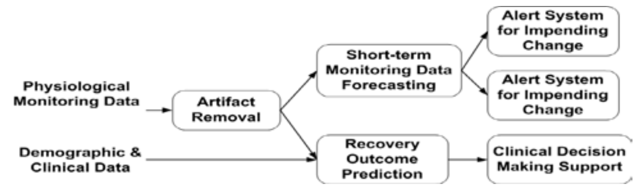


**Figure 3 Sub-modules of back-end computational intelligence module.**

Artifact Removal

Since the continuous physiological monitoring data is collected in a real NICU environment, as shown in Figure 4, artifacts in collected data is inevitable. According to our study, up to 24% of collected data can be corrupted by artifacts. The artifacts significantly change the characteristics of the underlying data, which makes accurate data modeling and effective data analysis impossible. Therefore, the objective of the "Artifact Removal" module is to first accurately detect artifacts in collected monitoring data and then replace the artifact data points with appropriate imputation values. To address this objective, we have proposed an effective and robust method in [8].

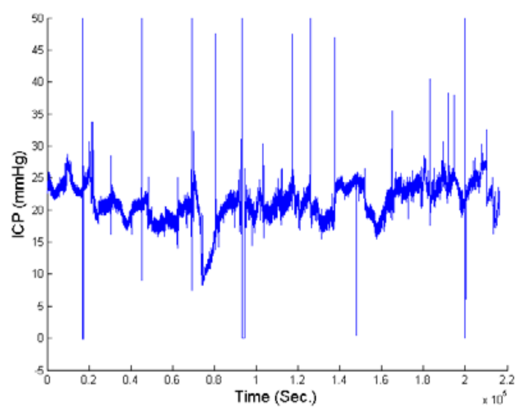


**Figure 4 Artifacts in physiological monitoring data.**

Short-term Monitoring Data Forecasting

The forecasting of monitoring data is to predict the upcoming physiological readings for a short period of time (15 mins ~ 1 hour). Short-term monitoring data forecasting is one of the most crucial computational intelligence modules in the system.

As shown in Figure 3, based on the forecasting results, the system will generate automatic alerts for significant changes of patients' physiological status. Take intracranial pressure (ICP) monitoring as an example. In NICU, ICP levels of patients are to be maintained below 20mmHg, and elevations of ICP levels require immediate treatments to avoid secondary insults to patients. Based on the forecasting results, automatic alerts will be generated, if ICP level of the patient is predicted to stay above 20mmHg for a considerable long period of time (e.g. > 5 mins), or if a significant rising trend is observed in the forecasted ICP.

In addition, short-term forecasting of monitoring data can also be used to assist clinicians to understand patients' response to given treatments. Take ICP as an example again. Treatments will be given to maintain patients' ICP levels below 20mmHg. However, different patients response differently to different treatments. Deciding the optimum treatment for a patient is challenging without full knowledge of patient's response to treatments. Short-term forecasting of ICP can address this problem. The short-term ICP is forecasted based on the assumption that no external events, e.g. clinical treatments, will happen. Therefore, if, after a particular treatment, the patient's ICP drops considerably lower than the forecasted value, this evidently suggests that the treatment is effective for the patient, and vice versa.

A neural network based predictive model is proposed in [9] to forecast the short-term mean values of monitoring data. Moreover, since the system is modular, other forecasting methods, such as [10], can be easily deployed to enhance the forecasting performance.

Recovery Outcome Prediction

When patients are discharged from NICU, the recovery outcome of patients are assessed based on the Glassgow Outcome Scale (GOS) [11]. The objective of the "Recovery Outcome Prediction" module is to estimate patients' recovery outcomes based on the integration information from both their clinical records and continuous physiological monitoring data.

The recovery outcome prediction module is another crucial computational intelligence module of the system. Patient outcome prediction results can serve as references to support clinical decisions. When a patient' status gets worse, neurosurgeons and neuroclinicians have to make a difficult decision on whether they should recommend the patient for surgery. Surgery may tentatively save the patient's life, but it involves high risk and does not guarantee long-term recovery. Moreover, surgery introduces heave financial costs to the patient's family, the hospital and the society. In this situation, prediction of the patient's recovery outcome can help neurosurgeons and neuroclinicians to assess whether it is worth to take the risk in employing more aggressive treatment options, such as surgeries. When the patient's outcome prediction indicates that it is unlike for the patient to survive or to recover beyond disability, passive treatment options may be suggested to avoid unnecessary suffering and financial costs to both the patient and the family.

## IV. CONCLUSION

This paper has proposed an integrated and intelligent system, iSyNCC, to enhance the effectiveness of patient monitoring and clinical decision makings in NICUs. The requirements of the system were investigated through interviews and discussions with neurosurgeons, neuroclinicians and nurses. Based on the summarized requirements, iSyNCC is designed to be a modular system. iSyNCC further follows a front-end back-end 2-tier structure. iSyNCC integrates and stores patient information, which includes demographic data, clinical records, treatment records and multi-modal physiological monitoring data. iSyNCC also enables remote & centralized patient monitoring in NICUs. Moreover, data-driven predictive and analytic results from iSyNCC can be used to generate alerts for impending changes of patients' physiological status and to facilitate clinical decision makings. In short, with the help of iSyNCC, the efficiency of patient monitoring and treatment in NICUs can be greatly improved.

iSyNCC has been fully implemented and is currently being tested in a simulated environment of Neuro-Critical Care. In the next step, after iSyNCC has been fully integrated and tested under simulated environment, it will then be deployed to NICUs and tested under real critical care environment.

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## REFERENCES

[1] P. Jones, P. Andrews, S. Midgley, S. Anderson, I. Piper, J. Tocher, A. Housley, J. Corrie, J. D. Slattery, "Measuring the burden of secondary insults in head-injured patients during intensive care," *Journal of neurosurgical anesthesiology*, 6 (1):4-14, 1994.

[2] C. Robertson, A. Valadka, H. Hannay, C. Contant, S. Gopinath, M. Cormio, M. Uzura, R. Grossman, "Prevention of secondary ischemic insults after severe head injury," *Critical care medicine*, 27 (10):2086–2095, 1999.

[3] S. Wald and S. Shackford, "The effect of secondary insults on mortality and long-term disability after severe head injury in a rural region without a trauma system," *The Journal of trauma* 34 (3):377-382, 1993.

[4] H. Cao, L. Eshelman, N. Chbat, L. Nielsen, B. Gross, M. Saeed, "Predicting ICU hemodynamic instability using continuous multiparameter trends," Conf Proc IEEE *EMBC*, 3803-3806, 2008.

[5] J. Ghajar, "Traumatic brain injury," *The Lancet* 356 (9233):923-929, 2000.

[6] H. Gomez, J. Camacho, B. Yelicich, L. Moraes, A. Biestro, C. Puppo, "Development of a multimodal monitoring platform for medical research," Conf Proc IEEE *EMBC*, 2358 – 2361, 2010.

[7] I. Piper, G. Citerio, I. Chambers, C. Contant, P. Enblad, H. Fiddes, T. Howells, K. Kiening, P. Nilsson, Y.H. Yau, "The BrainIT group: concept and core dataset definition", *Acta Neurochirurgica*, 145:8, 615-629, 2003

[8] M. Feng , L Y Loy, F. Zhang , Z. Zhang, C. Guan. "Artifact removal in brain monitoring signals: a robust solution based on signal decomposition.",submitted to IEEE *EMBC* 2011.

[9] F. Zhang, M. Feng., J. S. Pan, L. Y. Loy, W. Guo, Z. Zhang, P. L. Chin, C. Guan, N. King, B. T. Ang, "Artificial neural network based intracranial pressure statistical forecast algorithm for medical decision support", submitted to IEEE *EMBC* 2011.

[10] R. Hamilton, P. Xu, S. Asgari, M. Kasprowicz, P. Vespa, M. Bergsneider, X. Hu, "Forecasting intracranial pressure elevation using pulse waveform morphology," Conf Proc IEEE *EMBC,* 4331-4334, 2009.

[11] B. Jennett, J. Snoek, M. R. Bond, N. Brooks, "Disability after severe head injury: observations on the use of the Glasgow Outcome Scale". *J Neurol, Neurosurg, Psychiat* 1981;44:285-293.