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Multi-signal Visualization of Physiology (MVP): A Novel Visualization Dashboard for Physiological Monitoring of Traumatic Brain Injury Patients

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***Abstract* — To prevent Traumatic Brain Injury (TBI) patients from secondary brain injuries, patients' physiological readings are continuously monitored. However, the visualization dashboards of most existing monitoring devices cannot effectively present all physiological information of TBI patients and are also ineffective in facilitating neuro-clinicians for fast and accurate diagnosis. To address these shortcomings, we proposed a new visualization dashboard, namely the Multi-signal Visualization of Physiology (MVP). MVP makes use of multi-signal polygram to collate various physiological signals, and it also utilizes colors and the concept of "safe/danger zones" to assist neuro-clinicians to achieve fast and accurate diagnosis. Moreover, MVP allows neuro-clinicians to review historical physiological statuses of TBI patients, which can guide and optimize clinicians' diagnosis and prognosis decisions. The performance of MVP is tested and justified with an actual Philips monitoring device.**

I. INTRODUCTION

Traumatic Brain Injury (TBI) is a serious health hazard worldwide, not only because of the high incidence of deaths they cause (22% of all TBI cases result in death), but also owing to the large number of individuals who are left with some kind of disability [1]. After the primary head injury, a TBI patient is likely to receive secondary brain damage due to intracranial hypertension or insufficient oxygen and nutrients supply to the brain. Therefore, the survival rate and final functional recovery outcome of a TBI patient are mainly determined by the neuro-critical care of the patient during the immediate days following the primary head injury [2,3].

To prevent TBI patients from secondary brain injuries, continuous monitoring of patients' physiological signals has become a golden standard for modern neuro-critical care units worldwide [4]. Some of the popular monitoring devices are Philips' Intellivue, GE's CARESCAPE, Draeger's Infinity and Datascope's Passport. However, the visualization dashboards of these existing monitoring devices suffer the following shortcomings:

- As shown in Figure 1, various physiological signals are displayed independently, and the correlations and associations among physiological signals can hardly be visualized.
- Only the physiological signals over a small time segment are reviewed. Reviewing the historical signals and trends, which is crucial for diagnosis and prognosis, is not possible. Although some statistics, such as mean, minimum and maximum, of the signals are aggregated overtime, these readings do not reflect the development trends and morphological details of the signals.
- The current dashboard lacks clear indications on the patient's current physiological status: is the patient in danger? Is the patient stable? How likely the patient is going to cross over to the "danger" status.

Figure 1.Example of existing visualization dashboard for continuously monitored physiological signals [5]

To address these shortcomings, this paper proposes a new visualization dashboard. We name the proposed dashboard the **M**ulti-signal **V**isualization of **P**hysiology (the MVP).

The rest of the paper is organized as follows. Section II surveys the desirable features for the proposed visualization dashboard; Section III then discusses the design of our proposed dashboard, MVP; Section IV describes the deployment details of MVP; and we finally conclude the paper in Section V.

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II. SYSTEM REQUIREMENT ANALYSIS

After interviews and discussions with neurosurgeons, neuro-clinicians and nurses in neuro-critical units, the key features that are desirable for the visualization dashboard are summarized as follows.

A. *Multi-signal display to highlight correlations among physiological signals.*

According to the previous studies [6], it has been discovered that various physiological signals are indeed correlated, and observing the dynamic relationship among physiological signals is crucial for diagnosing the patient's physiological status. For example, it is known that the Intracranial Pressure (ICP) and the Mean Arterial Pressure (MAP) are highly correlated. The difference between MAP and ICP gives us the Cerebral Perfusion Pressure (CPP), an important indicator for TBI patients' physiological health [7].

B. *Indication of patient status for fast diagnosis.*

Continuous monitoring of TBI patients is a labor-intensive task, which cause heavy workload on neuro-critical care units. Neuro-clinicians are always looking for a display, where the status of the patient is clearly indicated. This feature can assist neuro-clinicians to achieve fast diagnosis.

C. *Review of historical data.*

As neuro-clinicians analyze the current physiological readings, it is useful to have the historical readings as a baseline to guide the clinicians' judgment. Moreover, the historical trends of physiological signals also offer information on how the TBI patient is recovering. This information is valuable for neuro-clinicians to review their current treatment strategy and to guide their diagnosis and prognosis.

D. *Integration with monitoring device*

For ease of deployment, the visualization dashboard should be versatile and should be able to integrate with current monitoring devices.

III. SYSTEM DESIGN

The proposed visualization dashboard, MVP, is designed closely based on the needs of neurosurgeons, neuro-clinicians and nurses, as summarized in Section II. MVP is composed with two components: visualization of current physiological readings and visualization of historical readings.

A. *Visualization of Current Readings*

Figure 2 graphically illustrates the visualization component for the current physiological readings. Novel features are employed in the visualization component to allow clinicians to better interpret the physiological readings and to achieve fast and accurate diagnosis.

1) Multi-signal Polygram Visualization

Instead of being displayed separately, in the proposed design, various physiological signals are collated and displayed in one multi-signal polygram. Figure 2 demonstrates an example, where 6 different physiological signals are displayed together. Note that: although only 6 signals are showcased in the example of Figure 2, the polygram graph can be customized for any number of signals.

As shown in Figure 2, live readings of various physiological signals are displayed at the corner of the polygram. Moreover, "reading pointers" are employed to graphically and dynamically represent the corresponding readings. This feature introduces a paradigm shift. Instead of making diagnosis by analyzing a bunch of numbers, neuro-clinicians now can make their decision by observing the "shape" of physiological readings. This transforms the diagnosis process to be more visual, more straightforward and thus more intuitive.

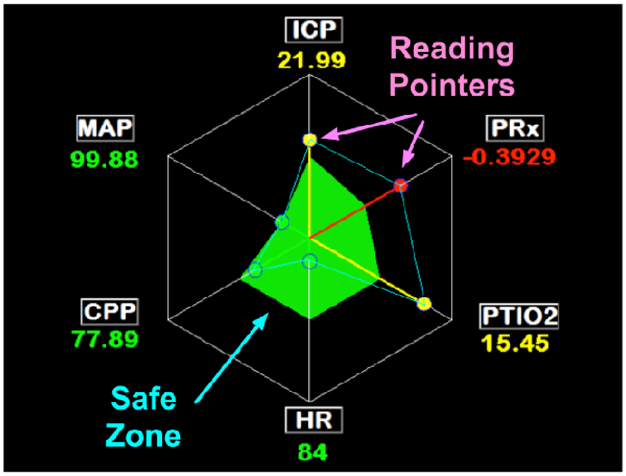

Figure 2. Visualization component for current physiological readings. Notations: ICP – Intracranial Pressure, PRx – Correlation index between ICP & MAP, MAP – Mean Arterial Pressure, CPP - Cerebral Perfusion Pressure, HR – Heart Rate, PTIO2 – Cerebral Tissue Oxygenation index

2) Highlight of Safe/Danger Zone

In our design, we have also introduced the concept of "zone", where users can define one or multiple zones based on their application. In the example of Figure 2, a "safe zone" is defined. To complement, users may also define a "danger zone". The number and the definition of zones are flexible and can be customized to suit the needs of different applications. Based on their requirements, the user can divide the polygram into any number of zones with any shapes.

The concept of "zones" allows neuro-clinicians to quickly diagnose the current status of TBI patients. If the reading ponters of the patient stay pretty much within the "safe zone", it is clear that the patient is doing fine; otherwise, if the readings are close to the "danger zone", then it may act as an alert to alarm neuro-clinicians to pay more attention.

Figure 3. Example of color definition to indicate various patient statuses.

3) Colors for Status Indication

We also make use of colors to highlight the different patient statuses. For example, as shown in Figure 3, we use "green" to indicate "safe", "red" to indicate "danger" and "yellow" to indicate the status in between. This is an intuitive color definition. Nevertheless, users are allowed to flexibly customize the color definition for various applications.

As illustrated in Figure 2, both the physiological readings and the corresponding pointers are coloured based on the current status of the patient. Moreover, the colours of the readings and pointers will change dynamically as the patient status changes.

With the polygram, the concept of "zone" and the usage of colours, our proposed visualization design, MVP, allows neuro-clinicians to collate information from various physiological signals, to visually appreciate the current patient status and, ultimately, to make fast and accurate diagnosis. These features also provide the clinician a comprehensive way to explain the current status of the patient to the family.

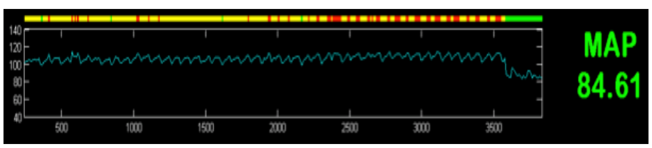

Figure 4. Visualization of historical physiological readings.

B. *Visualization of Historical Readings*

Figure 4 visualize the historical physiological readings of the Mean Arterial Pressure (MAP). The visualization component for historical readings is composed with three parts:

1) Historical reading chart

The historical reading chart is a chart that displays the previous physiological readings over a user-specified horizon of time. The display time horizon is again adjustable to enable users to investigate development trends under various time-resolutions.

2) Color bar for historical statuses

Colors are also used in the visualization of historical readings. On top of the historical reading chart, a color bar is deployed to present the physiological status that the patient has previous gone through. Following the same color definition in Figure 3, if a patient's color bar is majorly green, it implies that the patient has been mainly stable over the corresponding time horizon; on the other hand, if many red spots are observed in the color bar, then it indicates the situation of the patient is quite severe and he/she should require close monitoring.

3) Display of Current Reading

As shown in Figure 4, the current reading of MAP is also displayed at the right corner of the dashboard. The display of current reading allows clinicians to correlate the historical and current readings, and it also allows clinicians to monitor the current physiological status while reviewing the historical trends.

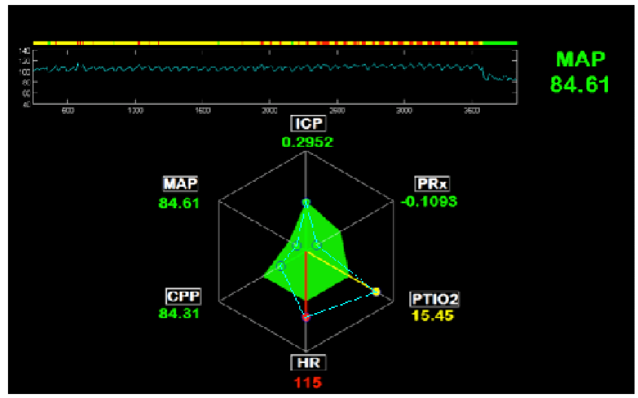

Figure 5. Integration of both visualization components for current and historical physiological readings.

IV. System Deployment

As shown in Figure 5, the proposed visualization dashboard, *MVP*, is the combination of both visualization components for the current and historical readings. To test the performance of our design and implementation, we have deployed *MVP* onto the Philips *Intellivue* MX800 system. Figure 6 shows a snapshot of *MVP* working on *Intellivue* MX800. According to our test, *MVP* is able to smoothly display all readings and charts in real time on MX800. In addition, owing to the advanced design of MX800, the user is allowed to freely switch between the existing visualization dashboard and our proposed *MVP*. Note: although the proposed visualization dashboard is tested on the Philips *Intellivue* system, *MVP* is a versatile design that can be applied to most monitoring devices.

The proposed *MVP* has also been included into the framework of iSyNCC [8], an intelligent system for effective patient monitoring and treatment of TBI patients.

Figure 6. Deployment of proposed visualization dashboard to Philips *Intellivue* MX800.

V. Conclusion

We observe that the visualization dashboards of most existing monitoring devices cannot effectively present all physiological information of TBI patients and are also ineffective in facilitating neuro-clinicians for fast and accurate diagnosis. To address these shortcomings, we proposed a new visualization dashboard, *MVP*. *MVP* makes use of multi-signal polygram to collate various physiological signals, and it utilizes colors and the concept of “safe/danger zones” to assist neuro-clinicians to achieve fast and accurate diagnosis. Moreover, *MVP* allows neuro-clinicians to review historical physiological statuses of TBI patients, which can guide and optimize clinicians’ diagnosis and prognosis decisions. The performance of *MVP* is tested and justified with an actual Philips monitoring device, *Intellivue* MX800.

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