A Preliminary Study of Monitoring Physical Tiredness Using Smartwatches and OGC IoT Standards

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ABSTRACT

The intensity of physical activity of employees can increase their physical tiredness, which is known as one of the most important work-related hazards. Tiredness can negatively impact cognitive condition and situational awareness, leading to work-related injuries or fatalities. In this work, we propose an initial study of an OGC standard-based interoperable monitoring system that leverages IoT capabilities to estimate physical tiredness in real-time, using a smartwatch. This can be used as an early warning system to prevent injuries due to tiredness. The feasibility of the proposed system is evaluated in an industrial environment with 7 workers and 2 work types. The intensity of physical activities and resting phases of work are reflected in employees' tiredness. The proposed approach can be used to enhance safety and risk management in a work environment.

1. Introduction

Tiredness negatively impacts the cognitive condition of people (e.g., drivers, healthcare team, mechanics, electricians, etc.), and impairs their situational awareness (Lerman, et al., 2012; Zhang et al., 2015). The reduced precaution, poor response time, and decision-making failure (Lerman, et al., 2012) can lead to lower performance and productivity, or drive to undesired incidents, illness, injuries, or even death. The recent report of the U.S. Bureau of Labor Statistics on the National Census of Fatal Occupational Injuries in 2020 indicated that 47.4% of workplace fatal injuries in 2020 were in transportation and material moving occupations and construction and extraction occupations. Additionally, there are around 5,000 fatal work injuries recorded per year between 2010 to 2020, with a work-related death every 111 minutes in 2020 in the US (Census of fatal occupational injuries summary, 2020).

These statistics show that despite all the occupational health and safety codes and regulations, work injuries and fatalities persist, and a safety monitoring system for an early attempt to address tiredness is crucial to enhance safety, decrease incident occurrence, and prevent fatalities.

Traditionally physical activity and physical fatigue were monitored by self-report questionnaires such as the Rating of Perceived Exertion (RPE) (Korshøj et al., 2022), the Fatigue Severity Scale (Krupp et al., 1989), and the Fatigue Assessment Scale (Michielsen et al., 2003). But self-report questionnaires are not a suitable method for continuous and real-time monitoring of physical tiredness. Since the cognitive and physical function of a tired person is impaired, a continuous and real-time system for monitoring physical tiredness can improve risk management to prevent potential injuries.

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With the rise of the Internet of Things (IoT), it is now possible to have an interconnected network of sensors that can communicate and share data through the cloud (Li et al., 2015). Smartwatches are a suitable and feasible alternative for continuous real-time monitoring of physical conditions since they contain a wide variety of sensors embedded in them, and they can communicate the data with a third-party person (Saheb et al., 2022). Additionally, smartwatches are everyday devices that people are used to wearing so that it would be easier for people to adopt. They can be a part of an early warning system to collect the Heart Rate (HR) and use it to estimate tiredness and notify a third-party person in case of an emergency. In this research, we focused on estimating physical tiredness using smartwatches.

HR monitoring has been used for many years for different purposes. Strath et al. (2000) showed that HR is correlated with energy expenditure, and it can be used as an indicator for free-living physical activity. Lee et al. (2023), also, proved the correlation between the fatigue level of construction workers calculated from their HR reserve and the one from the self-reports. This is while Korshøj et al. (2022) study revealed that PRE reports are not enough for monitoring the intensity of physical activity and adding an HR monitoring system is recommended.

Collecting a large amount of information using IoT, or smart sensors is possible now. However, interoperability and scalability remain to be two major challenges. In an interoperable system, data is exchanged without requiring any interpretations, as it is understandable by each part of the system (Liang & Huang., 2013; Jazayeri et al., 2015). In a scalable system, the increase in the size of data will not affect the performance of the system (Bahmani et. al, 2021). On the other hand, an open standard-based architecture can facilitate both the interoperability (Liang & Huang., 2013; Liang et al., 2020) and scalability (Lopez-Pellicer et al., 2012) of a system.

To enable scalability and interoperability, the real-time HR data is pushed to the Open Geospatial Consortium (OGC) SensorThings Application Programming Interface (STA) (Liang et al., 2016). The OGC STA open standard data model facilitates working with various proprietary data formats, communication protocols and web interfaces. In addition to the scalability and interoperability, the OGC STA data model enables geospatial and temporal location-based queries in an IoT system. In this paper, we focus on physical activity as the main source of physical tiredness since it can be estimated and monitored by HR, in real-time using the smartwatch. Additionally, the OGC STA observation from the smartwatch can be further used in geospatial analysis such as the association between tiredness and location of the work (e.g., work activities associated with various field locations).

The contributions of this study are

1. Using IoT as an early alerting system to collect persons' physical tiredness using smartwatches
2. Share real-time physical tiredness information for safety management policies
3. Demonstrating the OGC STA open standard can enable interoperability and scalability to our alerting system
4. Integrate an HR-based physical tiredness estimation method with OGC STA open standard

Preserving and protecting the worker's privacy is one of the main criteria for adapting IoT technologies in the industry. As we are evaluating the human subjects in this study, ethics approval was granted for this work. In this paper, we haven't discussed ethics approval, security, and privacy. To apply the proposed method to a large-scale product that can be adopted by the public, detailed, scalable user privacy research needs to be conducted on every layer of the system. Although privacy protection is outside this paper's scope, basic authentication and security authorization preserving techniques and user ID anonymization were applied to the proposed method.

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Moreover, this paper does not compare IoT and non-IoT methods, so the framework proposed here is not cross-validated with other non-IoT approaches. However, systematic validation of this research will be completed in future studies.

2. Methods & Data

This section describes the methodology used to monitor physical tiredness, focusing on architecture, application, and data model.

2.1 Architecture

The HR of each person is measured using the Photoplethysmography sensor of smartwatches with a sampling rate of 5 seconds. The smartwatch can be replaced with any IoT HR sensor due to the interoperability feature of the proposed system. The collected HR is then transformed and sent to the cloud through a smartphone paired with each smartwatch. On the cloud side, the collected HR gets enriched with the estimated level of tiredness.

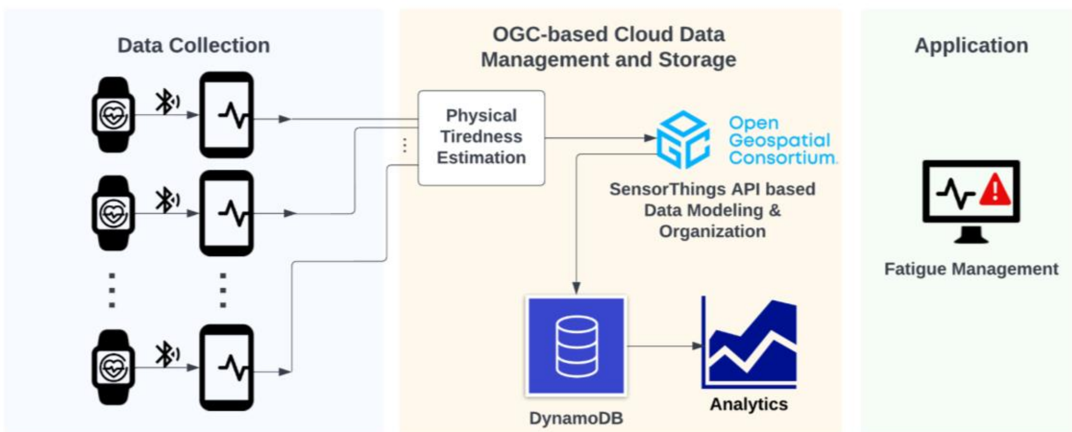

Figure 1: A high-level description of the architecture.

The calculation of physical tiredness is based on Muangsrinoon & Boonbrahm's (2017) method for caloric expenditure during physical activity. Then, the result is stored in a cloud database with respect to the OGC STA data model (Figure 1).
On the application layer, an alerting workflow is set when certain conditions are met so that predefined actions such as sending alerts based on a predefined rule will be executed (Figure 2).

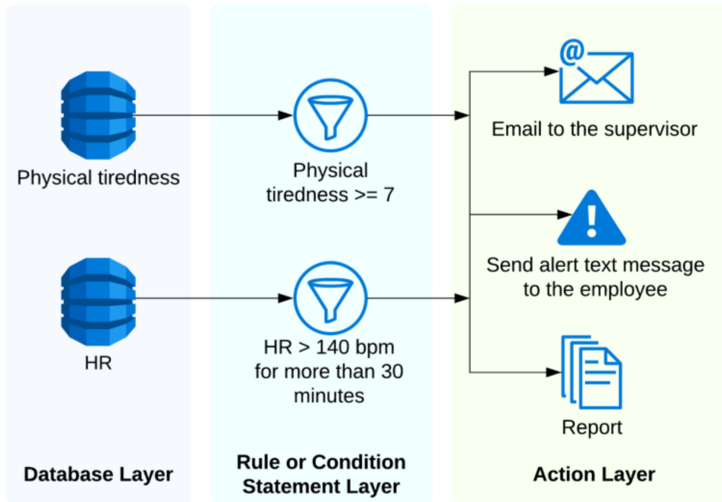

Figure 2: An example of an alerting workflow.

2.2 Data Model

The OGC STA data model is used for this study, which is a unified, open standard for connecting IoT devices, data, and applications. Figure 3 shows an example of the OGC STA data model used for HR monitoring for a specific Thing–a smartwatch.

2.3 Methods

To study the feasibility of the proposed architecture, the HR data of seven people with two different work types were collected for six consecutive days. Physical activity and breaks are part of the work types. After calculating the physical tiredness, it is calibrated based on experiments and workers' feedback on their regular working days so that "0" is "fresh" and "10" means "exhausted". Our intention was to identify whether workers reached the maximum tiredness limit we had allocated for them so that we could raise an alert or suggest break times, etc. In this paper, the association of their tiredness with time is studied.

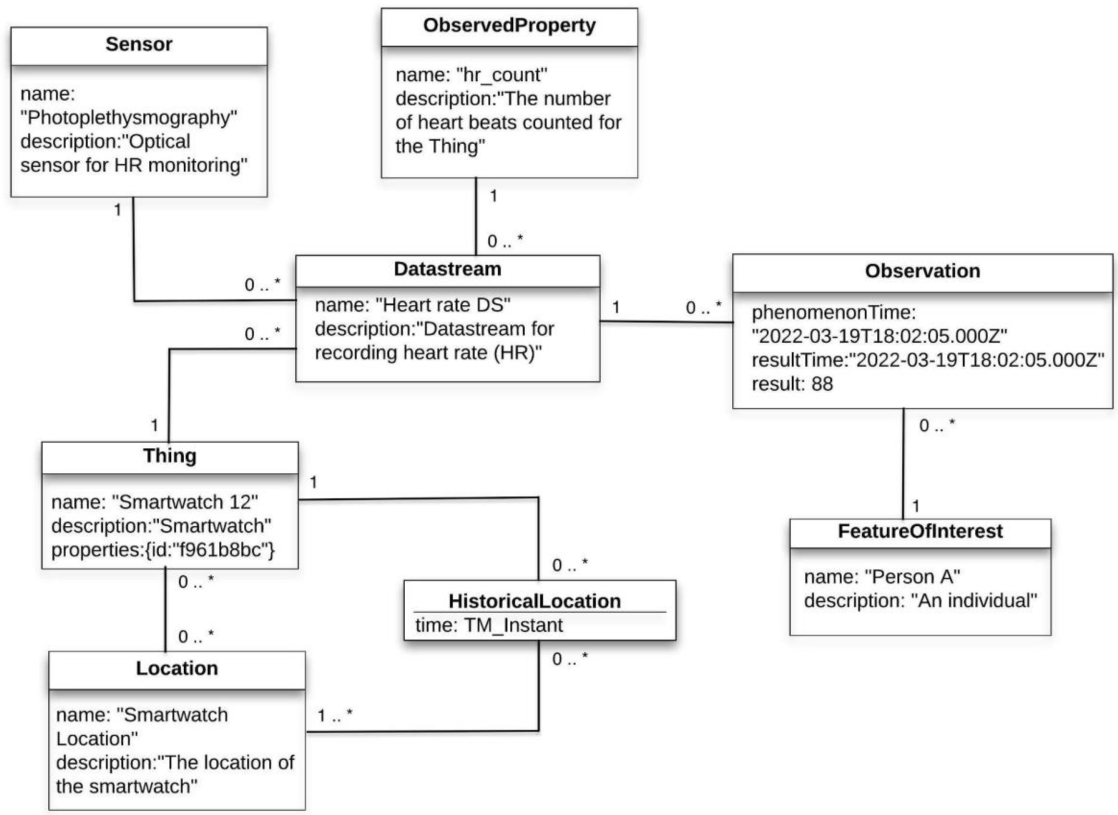

Figure 3: An example of the OGC STA data model for a selected smartwatch, where "*" represents "many" instances in the "0 to many" and "1 to many" relationships.

3. Result & Discussion

Our study revealed that physical tiredness is generally increasing with time for all people. It also reflects different phases of work, e.g., resting, working, and the intensity of physical activities. In the areas of "a", "b", and "c" the tiredness of "Person C" and "Person F" have decreased due to a drop in their HR, which can be interpreted as resting. Also, in region "d", physical tiredness has increased constantly (Figure 4).

As shown in Figure 4, the tiredness level of each person changes at a unique rate which is associated with their activity during the day. The same argument applies to their resting phase, which can be used as an indication of their break quality.

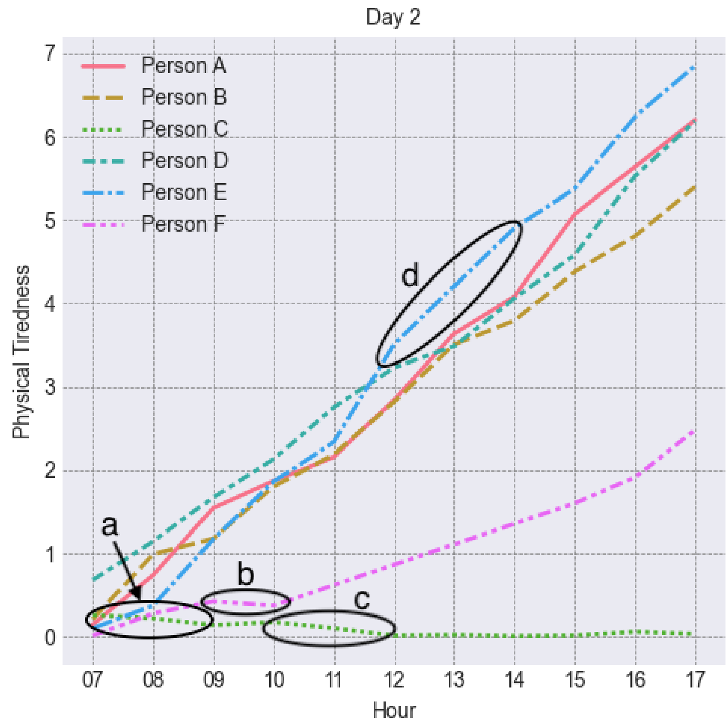

Figure 4: Physical tiredness variation of multiple people calibrated between 0 and 10 versus hours of a day. Each line illustrates the physical tiredness of a person.

Figure 5 illustrates that work type I requires a higher level of activity. As the physical tiredness was calibrated based on their regular working days, data shows that "Day 6" was the most intense day in terms of the physical activity of all the work types, especially work type I. Their tiredness reached the highest level of physical activity for work type I which was also confirmed by people in the field.

The proposed tiredness monitoring metric can be used to identify persons' vulnerability due to physical activity over a work shift. As a case in point, a safety-related incident happened during our real-time monitoring of a team. Our observation validated that the tiredness level of that person was relatively high compared to his team members which resulted in the incident. This confirms that real-time monitoring of tiredness is essential, and our proposed alerting system can be used to prevent potential safety incidents.

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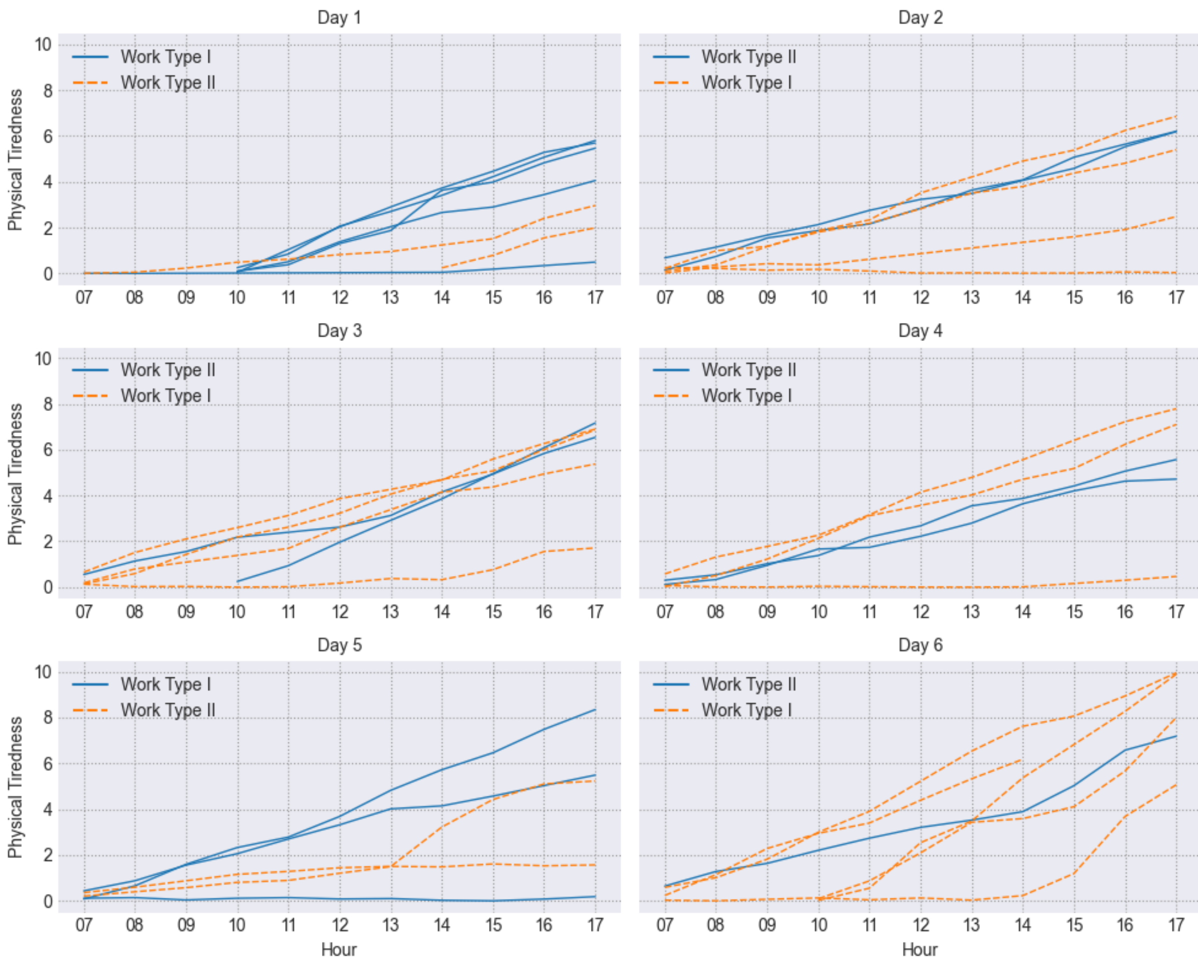

Figure 5: Comparing the physical tiredness of two different work types for different days.

4. Conclusion

This paper was an initial study on leveraging OGC STA open standard to a proposed tiredness monitoring system. The proposed system and metric were deployed and tested. The correlation of our physical tiredness metric with physical activity is validated from the field. It is a promising use of technology that can be implemented to improve safety and risk management in an organization.

One of the limitations and sources of errors of such a system is that the quality of sleep, consuming drugs, or alcohol, and other factors can play a role in biological metrics such as HR. This is while, tracking and monitoring workers outside of their working hours is not acceptable due to privacy concerns.

The OGC STA data model facilitates working with various proprietary data formats, communication protocols and web interfaces. In addition to the scalability and interoperability, the OGC STA data model enables geospatial and temporal location-based queries in an IoT system. This paper focused on physical tiredness, however, the OGC STA observations from the smartwatch can be further used in geospatial analysis such as the association between tiredness and the location of the work (e.g., work activities associated with various field locations). The OGC STA would make it easier to investigate the interaction of people and places. HR, the tiredness of the worker that is studied in this paper, age, gender, and level of experience are some of the attributes of a person that can be correlated with geospatial attributes of the place (workplace) such as temperature and humidity. The association of worker's attributes with location and assessing regional differences in a workplace will be studied in future works.

To apply the proposed method to a large-scale product that can be adopted by the public, detailed, scalable user privacy research needs to be conducted on every layer of a system.

To validate the proposed method in this paper, we conducted a self-report questionnaire at the end of each day for everyone. These subjective assessment reports confirm that our proposed method is accurately associated with the worker's observation of their tiredness. However, systematic validation of the proposed method is required for future studies to show the exact accuracy of the proposed method compared with self-report questionnaires. Also, we can compare this method with tiredness measured in non-IoT ways (e.g., efficacy at performing tasks).

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