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AN ALGORITHM FOR THE DECISION SYNTHESIS IN THE REMOTE MONITORING SYSTEM OF PHYSIOLOGICAL STATE OF WORKERS EMPLOYED AT HIGH-RISK FACILITIES*

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1. Introduction

Development of intelligent wearable, wearable/bio- (body-worn) and implant devices (smart watches, bracelets, bandages, patches, sensors placed under the skin or inside the body), Wireless Body Area Networks, Global Positioning System and mobile devices (smartphones, tablets) have opened up unprecedented opportunities to improve the safety of workers employed at high-risk facilities (HRFs), without limiting their professional activity, through remote monitoring of their health and environmental parameters.

The papers [1] propose the concept and architecture of an intelligent system based on IoT and e-health solutions for continuous remote monitoring of health status of workers employed on offshore oil platforms. In this paper, based on informative parameters of health status of workers employed in HRFs, a decision-making technique is proposed to identify the current health status of workers using fuzzy pattern recognition methods.

2. Problem statement

The methodology for organizing continuous remote monitoring of the physiological state of workers employed in HRFs is based on the concept of a person-centered approach to managing the personnel's health in the course of professional activities, IoT technology, e-health solutions and a functional model representing the implementation sequence of the following stages [1]:

(1) tracking, i.e., continuous remote monitoring of vital health status indicators of the personnel;
(2) monitoring and evaluation, i.e., comparison of monitored health indicators for compliance with standards in terms of medical requirements and specified restrictions;
(3) decision making, i.e., data processing and analytics to support decision making.

A person-centered approach to health and safety managing involves continuous remote monitoring of the workers' vital health indicators. The current (actual) situation here refers to a model (image) of the real health status of an employee, which is shaped upon the fact of deviation of continuously sensed health indicators from the norm.

Smart sensors embedded in wearable devices continuously monitor the workers' physiological health indicators (e.g., temperature, pulse, pressure, heart rate, complete blood count, etc.) at HRFs.

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In the course of continuous monitoring of the workers' health, a large amount of data on the workers' health status is generated, which complicates analysis through traditional methods. This leads to the development of intelligent algorithms for automatic data analysis and synthesis of diagnostic decision.

3. Problem solution

The IoT application continuously examines the sensed health data streams of all employees at HRFs, compares them with the normative ranges of changes in the values of health parameters previously recorded in the databases and monitoring system knowledge. IoT, instantly analyzing the current situation, reveals the facts of deviation of certain indicators from the norm and assesses the current situation. If the indicator values deviate from the norm, i.e., are beyond the normative range, the situation is assessed as critical and the monitoring system decides on the execution of specific actions (for example, an alarm for preventive medical intervention). In other cases, the monitoring system records the facts of deviation of certain indicators from the etalon value of the parameter within the standard range and sends this information to the system database. Information systematically accumulated over a certain period of time will identify current changes in the health status of each employee and make informed decisions on managing their personal trajectories.

In this case, depending on the deviation rate of certain indicators from the etalon value, the decision-making problem is reduced to the fuzzy images recognition. As a proximity measure of any two situations, the fuzzy equality (equivalence) or fuzzy inclusion rate, defined by formulas (1), (2) are used [2]:

$$\mu(A,B) = \underset{x\in X}{\&}(\mu_A(x) \to \mu_B(x)) = \min_{x\in X}\left[\min\left(\max(1-\mu_A(x),\mu_B(x)),\ \max(\mu_A(x),\ 1-\mu_B(x))\right)\right]. \tag{1}$$

$$\mu(A,B) = \underset{x\in X}{\&}(\mu_A(x),\mu_B(x)) = \underset{x\in X}{\&}(\max(1-\mu_A(x),\mu_B(x))) = \min_{x\in X}(\max(1-\mu_A(x),\mu_B(x))). \tag{2}$$

Here A is a fuzzy etalon image, B is a fuzzy real image of the health status on an employee employed at HRF, $X = \left\{x_i,\ i=\overline{1,m}\right\}$ denotes the worker's vital health indicator.

The formation of fuzzy etalon and real images of an employee's health status at HRF requires the use of a universal fuzzy scale. The advantage of the fuzzy universal scale is the ability to assess the deviations of various health parameters in a single term-set of linguistic variables [3]. Below, we propose an approach to constructing a fuzzy universal scale for assessing the deviation of generated health parameters from the norm, which covers the implementation of the following algorithm:

1. Based on normative data, the minimum and maximum values of the subject scale X are determined, i.e., upper (X_{ul}) and lower ($X_{l.l.}$) limits of parameter values.

2. Based on formula $X_{et.} = (X_{ul}.+Xl.l.)/2$, the etalon values of parameters are determined.

3. Taking into account the accepted switching thresholds and the equality of the two situations, the lower and upper limits of the range of parameters change are assigned a certain value from the interval [0, 1] (for example, 0.7).

4. Segments $[x_{l.l.}; x_{et}]$ and $[x_{et}; x_{u.l.}]$ are divided into several parts, depending on the choice of qualitative gradations of the linguistic variable "deviation of the etalon and real values of health parameter" and each level is assigned a fuzzy area from the interval [0.7;1]. The range of change of a linguistic variable depending on the degree of its severity, i.e., semantic interpretation of gradations, can be divided into several fuzzy intervals through the expert evaluation method; these intervals represent the range of the membership functions of fuzzy sets of verbal gradations of a linguistic variable (Table 1).

Table 1. Range of membership functions of fuzzy sets of verbal gradations "deviations of the etalon and real values of health parameters".

Linguistic variable	Term sets of a linguistic variable	Range of terms on the scale
Deviation of etalon and real value of health parameter	slight deviation	[0.95;1)
	very low deviation	[0.90; 0.95)
	low deviation	[0.85; 0.90)
	significant deviation	[0,80; 0.85)
	high deviation	[0.75; 0.80)
	very high deviation	[0.70; 0.75)

The membership functions of the real value of a specific health parameter (for example, temperature) on a universal fuzzy scale can be determined with the expert evaluation method based on the following expressions:

(1) $x = x_{et} \Rightarrow 1$ (i.e., absolute equality (or equivalence) of the etalon and real value of the medical parameter)

(2) $\left[x_{et} - \frac{x_{et}-x_{l.l.}}{6}\right] \le x < \left[x_{et} + \frac{x_{u.l.}-x_{et}}{6}\right] \Rightarrow 0,96$

(3) $\left[\left(x_{et} - 2\left(\frac{x_{et}-x_{l.l.}}{6}\right)\right) \le x < \left(x_{et} - \frac{x_{et}-x_{l.l.}}{6}\right)\right] \vee$
$\left[\left(x_{et} + \frac{x_{u.l.}-x_{et}}{6}\right) < x \le \left(x_{et} + 2\left(\frac{x_{u.l.}-x_{et}}{6}\right)\right)\right] \Rightarrow 0,91$

(4) $\left[\left(x_{et} - 3\left(\frac{x_{et}-x_{l.l.}}{6}\right)\right) \le x < \left(x_{et} - 2\left(\frac{x_{et}-x_{l.l.}}{6}\right)\right)\right] \vee$
$\left[\left(x_{et} + 2\left(\frac{x_{u.l.}-x_{et}}{6}\right)\right) < x \le \left(x_{et} + 3\left(\frac{x_{u.l.}-x_{et}}{6}\right)\right)\right] \Rightarrow 0,86$

(5) $\left[\left(x_{et} - 4\left(\frac{x_{et}-x_{l.l.}}{6}\right)\right) \le x < \left(x_{et} - 3\left(\frac{x_{et}-x_{l.l.}}{6}\right)\right)\right] \vee$
$\left[\left(x_{et} + 3\left(\frac{x_{u.l.}-x_{et}}{6}\right)\right) < x \le \left(x_{et} + 4\left(\frac{x_{u.l.}-x_{et}}{6}\right)\right)\right] \Rightarrow 0,80$

(6) $\left[\left(x_{et} - 5\left(\frac{x_{et}-x_{l.l.}}{6}\right)\right) \le x < \left(x_{et} - 4\left(\frac{x_{et}-x_{l.l.}}{6}\right)\right)\right] \vee$
$\left[\left(x_{et} + 4\left(\frac{x_{u.l.}-x_{et}}{6}\right)\right) < x \le \left(x_{et} + 5\left(\frac{x_{u.l.}-x_{et}}{6}\right)\right)\right] \Rightarrow 0,76$

(7) $\left[x_{l.l.} \le x < \left(x_{et} - 5\left(\frac{x_{et}-x_{l.l.}}{6}\right)\right)\right] \vee \left[\left(x_{et} + 5\left(\frac{x_{u.l.}-x_{et}}{6}\right)\right) < x \le x_{u.l.}\right] \Rightarrow 0,71$

(8) $(x_{u.l.} < x < x_{l.l.}) \Rightarrow 0$ (total deviation, i.e., critical situation).

Further, based on formulas (1) or (2), the fuzzy equality (equivalence) rate of fuzzy etalon and real images of the employee's health status are determined and decisions are made.

4. Conclusion

Continuous remote monitoring of the employee's status employed at HRFs provides information about their real time health. The proposed IoT platform-based algorithm automatically analyzed the data and synthesized a diagnostic decision that can be implemented in accordance with two scenarios: 1) Decision automatically made by the IoT application, as a response to the critical situation, instantly acts as a control action both for the wearable devices of workers (as an alarm) and for the emergency response service at HRFs; 2) Decision automatically synthesized by the IoT platform is sent to the responsible clinician for confirmation (CPS human in the loop).

Keywords: High-Risk Facilities, Internet of Things, Remote Monitoring System, Fuzzy Pattern Recognition.

AMS Subject Classification: 68M14, 68T30, 93C41, 93C62.

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