WEARABLE SMART SENSORS FOR HEALTH SECURITY IN TRANSPORT: THE CASE OF STUDY OF DIABETIC RISK MANAGEMENT THOUGHT ADVANCED DATA ANALYSIS APPROACHES INTEGRATED INTO ENTERPRISE PROCESS MODELS

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Abstract - The paper is focused on a pilot case of study about the implementation of smart health sensors in the public transportation sector. The case of study involves business processes of different companies working in transport services, garment manufacturing, and smart health Internet of Things (IoT) sensors. Specifically, the proposed work aims to prove how risk management can be controlled through Personal Protective Equipment (PPE) connected to a control room platform. The new risk management process is executed by means of a platform collecting driver data. The mapping of “AS IS” and the “TO BE” processes by means of the Business Process Modeling Notation (BPMN) approach, highlights the improvement of the procedures applied to predict the health risk, by enabling production and monitoring processes. All processes are described by a platform data flow represented by the Unified Modeling Language (UML) Use Case Diagram (UCD) diagram. Digital data is collected into a data warehouse enabling health monitoring processes. As far as concerns the specific risk addressed by this study the models analyzed in this paper are based on algorithms such as Autoregressive Integrated Moving Average (ARIMA) and Long Short Term Memory (LSTM), both able to predict health status and dangerous conditions of the drivers such as hypo- and hyper-glycemia for Diabetes Mellitus cases. The case study has been developed within the framework of Smart District 4.0 (SD 4.0) project.

Keywords - We would like to encourage you to list your keywords in this section.

I. INTRODUCTION

In this paper is discussed the case of study of synergies between companies working in different marketing sectors. The company’s cooperation is oriented on production of wearable Internet of Things (IoT) sensors to embed into worker garments, thus realizing innovative Personal Protective Equipment (PPE), and improving the control of the transportation risk associated with driver health monitoring. A unique Information Technology (IT) collaborative framework, developed within the Smart District 4.0 (SD 4.0) project, initiative funded with the contribution of the Italian Ministry of Economic Development, sustaining the digitization process of the Italian Small Medium Enterprises (SMEs), has been developed integrating all processes regarding the analyzed pilot case study. The state of the art reported below, introduces shortly the general framework of the case study. The transport service and industries are moving on the use of Artificial Intelligence (AI) applications to obtain information about driver style, driver behavior and performance [1]. Surely, the driver check is also important for health condition monitoring [2]-[4] to preserve security for passengers. Health wearable [5] and smart sensors [6] are able to remotely monitor the physiological status of the patient in real time, as for IoT applications. These technologies matched well with the possibility to remotely control the driver's health status. Driver predictive diagnosis can be achieved by means of telemedicine platforms based on AI algorithms running within a virtual control room monitoring patients [7],[8]. A particular attention about health risks, is about the diabetes prediction [9]-[15], which can be performed by different advanced algorithms such as Autoregressive Integrated Moving Average (ARIMA) [16], and Long Short Term Memory (LSTM) [17]. In order to check performance of the algorithms models, in literature are used open dataset such as DINAMO [18], thus suggesting the strategy to check the Decision Support System (DSS) of the health control room of the pilot case of study. The proposed paper follows the technologies of the state of the art, by showing the main phases of the research development about process and data flow design, platform design, control room development, and comparison of
algorithms predicting driver health status. The pilot case study is suitable to construct a telemedicine platform involving different system actors [19].

1.2. Specific Correlated Works

Control rooms in telemedicine applications are important challenges in modern research. Specifically, diabetic risk prediction [20], [21] can be analyzed by means of dashboards visualizing outputs of machine learning algorithms. In order to optimize supervised algorithms, can be adopted augmented data approaches optimizing training models [20]. A good design approach for telemedicine platform design is to design an information technology infrastructure capable to connect different system actors (doctors, patients, hospital service, etc.) [22],[23]. Concerning diabetic risk analysis other techniques can be considered enforcing the analysis, such as statistical and image processing methods [24],[25]. A complete framework of a telemedicine platform could include different data and information to control the diabetic risk.

1.3. Main Project Architecture: Requirements and UML Data Flow Design

The basic idea of the pilot study is to integrate appropriate sensors into workwear of drivers of public transport services, in order to enable the use of the health detected data for monitoring activities, and to facilitate prediction and timely reporting of critical and potential danger conditions for drivers and passengers. The IoT sensors, produced by an industry working in medical device production (Emtesys srl), are able to monitor biometric parameters focusing the attention on critical physiological conditions: these preventive and protective measures make it possible to better manage the safety of the transport company's drivers and, consequently, that of passengers. The data acquired through IoT devices flow into the project platform named Smart District 4.0 (SD 4.0), for the purpose of monitoring the operator through an alert system aimed at both the driver (on-board devices) and supervisors (control room monitoring process). In case of physiological parameters over a threshold, the SD 4.0 platform allows the doctor to assign an emergency code enabling a specific health security process. Another company (Innex srl) has the rule to integrate the medical smart sensor into worker garment allowing the wearable application. The smart sensors analyzed in the preliminary part of the project are:

- PIXOTEST (HbA1c glycated hemoglobin test and lipid profile);
- IRIS EVOLUTION PLUS (glucometer);
- IRIS BP103 (sphygmometer);
- GLUNOVO CGM (glucose measurement useful for Diabetes Mellitus monitoring).

As illustrated by the simplified architecture of Fig. 1, the goal is to integrate sensors and monitoring services (enabled by a control room), in order to detect physiological parameters, and, consecutively to control the transportation risk. The architecture is representative of the future business model of the pilot company (transport company), integrating production activities of other companies producing garments and medical IoT sensors, and interacting with other actors involved in the security system. Figure 2 shows the data flow of the system architecture, expressed by a Unified Modeling Language (UML) Use Case Diagram (UCD). In the detailed diagram are indicated the following actors with their specific functions:

- Transport company (pilot company as final user of the project facilities) uses SD 4.0 data warehouse and associated services (control room, driver health status dashboards);
- Driver manager manages driver security interacting with doctor (risk management);
- Doctors checks real time driver status interacting with driver manager;
- Emtesys srl (supplier of the medical smart IoT devices) makes available data of all sensors;
- Innex srl (supplier providing garments integrating smart medical sensors).

All data are collected in SD 4.0 framework enabling data storage, data transfer, data processing, and implementing the business process.

![Figure 1. Architecture involving the “TO BE” business processes.](image-url)
II.  “AS IS” AND “TO BE” PROCESSES: DESIGN OF THE BUSINESS MODEL

The “AS IS” process mapping provides the previous scenario of the transport company about security and driver health status checking procedure. The company managed the driver assignment by means the process illustrated in Fig. 3, where the driver, if passed the initial check of his health status (fever checking and directly asking the status), is pre-assigned for the travel; a further check establishes if the driver passed the periodic health examination by considering a delay margin; if the periodic medical examination is not performed, it is required urgently a new one by updating the driver list availability.

In Fig. 4 is illustrated the designed “TO BE” process involving the main actors. Before starting the activity, Emtesys srl, proceeds with a Deoxyribonucleic Acid (DNA) test on the drivers in order to detect any genetic predispositions to diseases, through the analysis of biological traces (saliva). Once the test has been performed, the IoT smart sensor configuration for the health status monitoring of a specific driver is defined. In case the driver needs to be monitored through the use of the GLUNOVO device, the SD 4.0 platform asks to the transport company the driver morphological profile (height, chest circumference, waist circumference etc.). This information is necessary for the production by Innex srl, of a tailor-made garment in which to integrate the specific device. The IoT data and results are transmitted to the SD 4.0 platform allowing data storage and data processing processes. The transport company establishes and activates the production of sensors and of related garments by deciding the monitoring procedure of each driver.

III.  THE CASE OF STUDY APPLIED TO DIABETES MELLITUS OF DRIVERS

Diabetes mellitus is a metabolic disorder that causes blood glucose levels to deviate from normal values and can lead in more or less long periods to serious health complications and in some cases, if not properly treated, even to death. Continuous Glucose Monitoring (CGM)
technologies (recording the level of glucose in the blood at intervals of a few minutes), could be used for the prediction of blood glucose concentration, by optimizing the glycemic control. In this direction, AI algorithms could provide more information about the risk of anomalous values of glucose in drivers assigned for specific travels. Furthermore, recently, machine learning and data mining techniques have reached a sufficient degree of maturity in the forecasting problems of time series, which include the applications of predicting blood glucose levels [9]-[15]. The goal of the case study, is the development of a software/hardware prototype alerting system based on the monitoring and prediction of the drivers' glucose level, and on the managing health risk, thus predicting glycemic spikes or drops during service hours. To do this, are provided to drivers, devices for monitoring of glucose which detect the concentration of glucose in the blood at regular intervals of 3 minutes. Specifically, is defined a methodology that allows the creation of a blood glucose level prediction system, in order to raise an alert in the event that the prediction moves outside the upper and lower threshold values. The alerting system is achieved through the development of a control room platform embedded in the SD 4.0 framework. The platform is based on machine learning algorithms, able to predict in the short or medium term (30/60 minutes) the driver's health status. This methodology is part of a more complex system in which a specialist doctor can analyze the glycemic index trend through the control dashboard, determining possible criticalities. From the study of the state of art it emerged that two of the most promising approaches are ARIMA and LSTM. These algorithms have been adopted to improve the driver health alerting system.

3.1. SD 4.0 Control Room Platform

The implemented SD 4.0 control room platform layout is shown in Fig. 5: the frontend interface indicates a field with a list of the different analyzed users, a list of smart sensors associated for each user, the user somatic characteristics (age, weight, height), and the real time trend of the blood glucose. The platform highlights the real time alerting conditions by automatically checking the overcoming of an upper and a lower threshold (hypo- and hyper- glycemia conditions, respectively). The data are sent by the GLUNOVO device to the SD 4.0 data warehouse (data collected into the Google Cloud Big Query, SQL like technology) through web service calls. In Fig. 6 is illustrated a zoomed image of the graphical dashboard plotting the glucose parameter.

3.2. Diabetes Prediction: ARIMA and LSTM Comparison

An important application of the control room platform is to predict glucose of drivers. The algorithms considered in the proposed analyses are ARIMA, and LSTM. The first approach is a statistical model, besides the LSTM is based on a specific recurrent neural network (RNN) architecture, designed to model temporal sequences and their long-range dependencies. Both the approaches have been tested by using the DINAMO dataset, an online public open dataset suitable for the diabetes analyses [9]. In Fig. 7 is illustrated an example of glucose level estimated by the ARIMA model by considering a window monitoring of 60 minutes, where the last 10 minutes are predicted. A good matching between actual and forecasting output is checked by confirming that the proposed algorithm is suitable for the specific dataset. The ARIMA (p,d,q) used approach, is based on the definition of an adaptive logic optimizing the parameters of the model p, q and d so that, with each new algorithm's execution, the best model is recalculated on the basis of the previous results. In this way, the trend of the series is predicted for each new algorithm running: this allows to eliminate the cases in which the model is wrong, due to the unexpected change in the trend of the series, by tracing in each step the current trend, and highlighting
cases in which the glycemic index is rising or falling quickly.

In Fig. 8 is illustrated the prediction results by adopting the LSTM model. Also in this case a good matching between the predicted and the actual values is observed.

The adopted LSTM model is characterized by the hyperparameters of Table 1:

<table>
<thead>
<tr>
<th>Layer (type)</th>
<th>Output shape [(Batch Size, Time Steps, Output Dimension); (Batch Size, Internal Units)]</th>
<th>Parameter number</th>
</tr>
</thead>
<tbody>
<tr>
<td>lstm_1 (LSTM)</td>
<td>(None, 96, 32)</td>
<td>4352</td>
</tr>
<tr>
<td>lstm_2 (LSTM)</td>
<td>(None, 16)</td>
<td>3136</td>
</tr>
<tr>
<td>dense_1 (Dense)</td>
<td>(None, 12)</td>
<td>204</td>
</tr>
</tbody>
</table>

Total parameters: 7692
Trainable parameters: 7692
Non-trainable parameters: 0

For the calculation of Root-Mean-Square Errors (RMSEs), seven models have been trained (one for each series of the glycemic index with sufficient training data), each one being trained for 30 epochs. Mean Squared Error (MSE) has been adopted as a loss function and RMSprop as an optimization algorithm. The average training time is 106 seconds. Figure 9 shows an example of a training curve of one of the trained models. In Fig. 10 is illustrated the LSTM model architecture adopted for the blood glucose prediction.

In Table 2 are listed the Root Mean Squared Error (RMSE) values for both the analyzed method.

<table>
<thead>
<tr>
<th>Method</th>
<th>RMSE (30 minutes)</th>
<th>RMSE (60 minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ARIMA</td>
<td>1.11</td>
<td>2.23</td>
</tr>
<tr>
<td>LSTM</td>
<td>2.75</td>
<td>3.13</td>
</tr>
</tbody>
</table>
, where the RMSE is defined as:

\[ \text{RMSE} = \frac{1}{T} \sum_{t=1}^{T} (\hat{y}_t - y_t)^2 \]

being \( \hat{y}_t \) is the predicted values, \( y_t \) are the observed values, and \( T \) is the number of observations.

Compared to the ARIMA-based model, the LSTM-based model is slightly less performing: the model based on ARIMA is the most performing in the 30 and 60 minutes with a RMSE (30 minutes) of 1.11 and a RMSE (60 minutes) of 2.23.

The training model has been carried out on the same Google Cloud virtual machine with 16GB RAM and 2 vCPUs. In both cases the code was written in python using, for the ARIMA model, the statsmodel library, and for the LSTM-based model, the Tensorflow 2.0 library.

IV. DISCUSSION: LIMITATIONS AND PERSPECTIVES

The limitations of the proposed approach are mainly due to the implementation of the diabetic risk monitoring process. The use of the technology and the management of human resources executing the monitoring process, requires a systemic use of the control room platform: a good check of the driver activity can be performed by a real time monitoring approaches and by the identifying a security actor checking medical examinations status. The perspectives of the proposed research, is to adopt in the same platform the monitoring of other physiological data checking hypertension and heart risks thus increasing the security level travelling by bus.

V. CONCLUSIONS

The work is focused on the design of new business processes involving the production synergy of different companies working in service transportation, smart health medical sensors, and garment production. The collaborative actions between companies is improved through the use of a platform designed to manage all data fluxes of all the actors involved in the new macro-process managing production, and monitoring by a control room the transport security. Specifically, this pilot study presents the identification of a methodology based on process engineering, and machine learning implementation predicting glycemic index of drivers as an advanced alerting security system based on driver health risk estimation. The new macro-process has been implemented into a platform named SD 4.0 collecting all digital data, including data of the glucometer used for the experimentation for drivers glucose prediction. ARIMA and LSTM models have been adopted in order to compare the prediction performances. For the analyzed testing dataset ARIMA shows slightly better performance than LSTM one.

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