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IoT + DBMS = Periodic Summary of the Health Status of Remote Patients

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Abstract: There is a growing number of frail patients whose health conditions require constant monitoring by physicians. Unfortunately, the budget restrictions of hospitals and the concomitant resolution of patients to stay home require that this control is to be carried out remotely. Today, Internet of Things (IoT) wearables are the most promising technology solution for sensing patients' physiological values 24/7. Those measurements need to be stored permanently and then processed in order to provide support to physicians in charge of taking in-time clinical decisions consistent with the patient health status. This paper elaborates on the marriage of the IoT and DBMS technologies. In detail, a PostgreSQL relational database collects the Patient-Generated Health Data (PGHD), while a set of SQL views implement standard summary statistical indicators.

Keywords: Internet of Things; Healthcare; Patient-Generated Health Data (PGHD); Remote Monitoring; PostgreSQL, SQL, Summary Statistics.

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1. Introduction

With advances in mobile health technologies, patients are able to generate more health-related data than ever before. Therefore, the best way to provide an adequate assistance to elderlies consists in resorting to solutions based on the Internet of Things (IoT). PGHD can consist of clinical measurements about blood pressure, heart rate, oxygen saturation, taken by patients themselves or their caregivers in the 24 daily hours. PGHD are a continuous stream of data. Their use in clinical practice allows monitoring the value of vital parameters of remote, fragile patients. Interesting proposals of IoT systems that do this have already appeared [1–4]. The relevance of IoT remote health monitoring systems has been reaffirmed by Narasimharao et al. [5] in 2023.

Previous studies have proposed solutions based on the IoT that allow the physicians to see the PGHD graphically on a mobile phone almost in real-time [4]. In the present paper another strategy of usage of PGHD is sketched. We assume that the PGHD are collected in a DataBase. The objective is to provide physicians with summary statistics based on physiological measurements over a given time interval (e.g., daily, weekly, etc.). The DataBase Management System is the best software technology that suits such a need. In detail, a PostgreSQL relational database suitable to collect PGHD has been designed and implemented; the database is enhanced by a set of SQL views which compute standard summary statistics. The solution is parametric, so the interval of investigation can be customized according to physician's needs. Adding to the graphical view of PGHD summary statistics about them enriches the basis on which physicians can make data-driven clinical decisions.

The implementation of an effective Long-Term Care service implies that different channels are adopted in a consistent and coordinated way. A database collecting PGHD is one of those medium. In 2022, Siddik et al. [6] pointed out that the combined usage of IoT, cutting-edge computing (mostly cloud computing), DBMSs and visualization tools is the best strategy for implementing a modern system for the management of a large number of illnesses; while Kawu et al. [7] complement [6] by providing an up-to-date survey about the state of the art and the open issues in the integration of the diverse sources of PGHD into the already existing health databases.

In [6], the PGHD stored into the database are retrieved to be visualized in a dashboard in order to show the patient's health conditions to the physicians. Our proposal emphasizes the need to process the PGHD to extract statistics over a given time interval. Those statistics complement the information that physicians can derive by looking at the instantaneous values of physiological parameters, so enriching the basis on which they take the clinical decisions. As far as we know, no previous studies focused on the same issue.

The remaining part of the paper is structured as follows. Sec.2 provides an overview about the structure of the database and the summary statistics taken into account; while Sec.3 details the proposed solution by creating a sample database and by showing the SQL code of a set of views that compute the summary statistics. Sec. 4 ends the paper.

2. Materials and Methods

2.1. The database

Databases about PGHD are a precious intangible asset that allow the implementation of quantitative methods as an alternative to qualitive ones. By querying these databases, it is possible to build summary statistics over fixed periods of time.

Fig. 1 shows the database conceptual schema. As DBMS we adopted the open-source PostgreSQL, ver.14. PostgreSQL is an object-relation system that offers a robust support to the JSON data type. The latter allows to store into the database unstructured data as well. A certain degree of flexibility is highly recommendable in our case, because it helps dealing with attributes `p_description` and `m_value` which are containers of manifold fields.

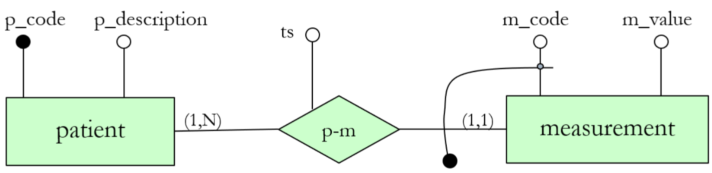


Figure 1. The E-R schema of the database.

Fig. 2 shows the PostgreSQL's SQL/DDL scripts of the two tables of the designed database.

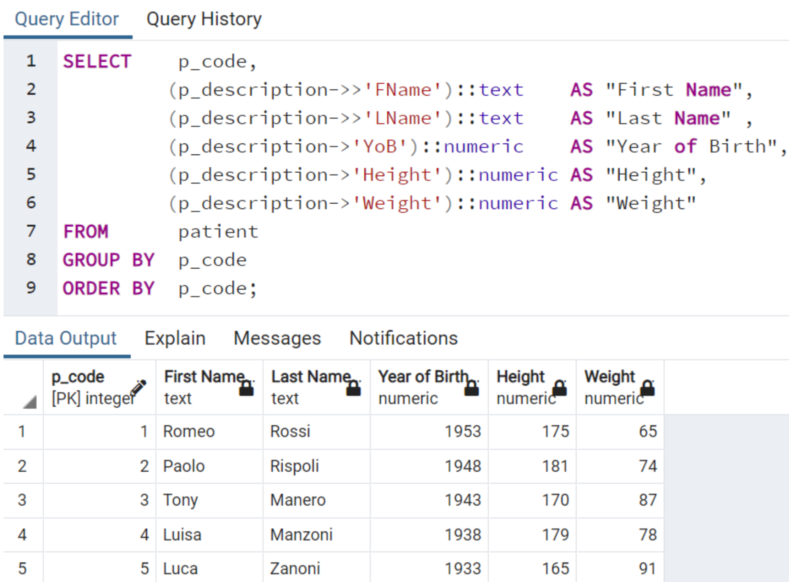
```
CREATE TABLE patient (
p_code        int    PRIMARY KEY   NOT NULL,
p_description JSONB                NOT NULL );


CREATE TABLE measurement (
m_code   int    NOT NULL,
p_code   int    NOT NULL,
ts  TIMESTAMP NOT NULL,
m_value JSONB NOT NULL,
PRIMARY KEY (m_code, p_code),
FOREIGN KEY (p_code) references patient(p_code)
        ON UPDATE CASCADE );
```

Figure 2. The SQL/DDL of the database tables.

2.2. Summary Statistics

Summary statistics comes under the umbrella of descriptive statistics. Summary statistics consists of a set of metrics that provide insights about the behavior of a data set. To support physicians in making a "data-driven" evaluation of the health status of a remote




```sql
SELECT    p_code,
         (p_description->>'FName')::text    AS "First Name",
         (p_description->>'LName')::text    AS "Last Name" ,
         (p_description->'YoB')::numeric    AS "Year of Birth",
         (p_description->'Height')::numeric AS "Height",
         (p_description->'Weight')::numeric AS "Weight"
FROM      patient
GROUP BY  p_code
ORDER BY  p_code;
```

	p_code [PK] integer	First Name text	Last Name text	Year of Birth numeric	Height numeric	Weight numeric
1	1	Romeo	Rossi	1953	175	65
2	2	Paolo	Rispoli	1948	181	74
3	3	Tony	Manero	1943	170	87
4	4	Luisa	Manzoni	1938	179	78
5	5	Luca	Zanoni	1933	165	91

Figure 3. The patients data set.

patient, the following metrics are provided to him: minimum (min), maximum (MAX), range (range), average (AVG), standard deviation (STD), and coefficient of variation (CV = STD/AVG). Standard deviation is defined as the square root of the variance. Variance measures how far each number in a data set is from the average. A low variance indicates that the values tend to be close to the mean. Variance equals to zero means that alle the values in the data set are equal to the average. In turn, standard deviation is a measure of the amount of variation or dispersion of a set of values. A low standard deviation indicates that the values tend to be close to the mean (also called the expected value) of the set, while a high standard deviation indicates that the values are spread out over a wider range.

Physicians know very well that it is one thing to calculate the standard deviation from a data set and another to interpret it and find out what it is telling us about the data set. The value of CV is relevant because it tells us if standard deviation is low or high, since it links the standard deviation to the mean. In simple words, CV allows to state if STD is high or low. CV < 1 means that STD is low (it also tells us that STD <= AVG); while CV > 1 means that STD is high (it also tells us that STD > AVG).

All physicians are able to interpret the values of the six metrics mentioned above, once they are made available to them. This is the role played by the solution sketched in this study.

3. Results

3.1. A sample database

As a proof of concept of the perspective adopted in this study, the database was structured in terms of 5 patients and 24 measurements for each of them. The field `m_description` comprises the following data: `FName`, `LName`, `YoB` (Year of Birth), `Weight`, and `Height`; while the field `m_value` collects data about: `temp` (temperature), `HRate` (Heart Rate), `SPO2` (Oxygen Saturation), `SBP` (Systolic Blood Pressure), and `DBP` (Diastolic Blood Pressure). This set of human physiological parameters is taken into account systematically in studies concerning the monitoring of patients' health status (see, for instance, [8–10]). The measures refer to the 24 hours of a single day (06 June, 2023), moreover (without loss of generality) the timestamps are the same for each patient (i.e., '`2023-06-01 00:01:01`', '`2023-06-01 01:01:01`', and so on). Fig. 3 shows the content of the `patient` table and the SQL query that displays it; while Fig. 4 shows the measurements data set.

```
_Measurement data set.csv
"p_code","m_value"
1,"[60, 61, 63, 64, 62, 67, 68, 69, 69, 70, 67, 68, 69, 68, 66, 71, 73, 74, 78, 75, 78, 76, 68, 63]"
1,"[93, 93, 92, 92, 94, 90, 91, 89, 88, 89, 90, 89, 87, 86, 91, 90, 92, 89, 88, 89, 90, 92, 94, 93]"
1,"[111, 112, 113, 112, 112, 114, 120, 122, 122, 124, 122, 125, 126, 127, 121, 122, 120, 122, 127, 129, 120, 116, 112, 111]"
1,"[74, 76, 76, 75, 78, 76, 78, 77, 79, 76, 75, 76, 77, 78, 74, 76, 76, 78, 77, 79, 76, 75, 73, 72]"
1,"[36.5, 36.5, 36.7, 36.8, 36.5, 36.4, 36.5, 36.8, 36.5, 36.7, 36.5, 36.5, 36.8, 36.5, 36.5, 36.9, 36.7, 36.4, 36.5, 36.8, 36.5, 36.5, 36.5, 36.5]"
2,"[112, 112, 114, 117, 118, 116, 120, 122, 121, 120, 119, 122, 124, 122, 119, 120, 121, 122, 123, 124, 123, 120, 118, 115]"
2,"[36.5, 37.5, 36.5, 37.5, 36.5, 37.5, 36.5, 37.5, 36.5, 37.5, 36.5, 37.5, 36.5, 37.5, 36.5, 37.5, 36.5, 37.5, 36.5, 37.5, 36.5, 37.5, 36.5, 37.5]"
2,"[61, 63, 64, 68, 65, 64, 68, 70, 73, 73, 78, 77, 81, 83, 78, 83, 80, 83, 88, 82, 80, 80, 75, 72]"
2,"[94, 93, 94, 95, 94, 93, 92, 93, 94, 94, 94, 92, 90, 91, 92, 93, 94, 92, 91, 90, 91, 92, 94, 95]"
2,"[77, 76, 76, 76, 76, 76, 80, 82, 86, 86, 86, 85, 88, 85, 84, 82, 83, 84, 86, 89, 89, 87, 83, 82]"
3,"[125, 122, 128, 124, 127, 125, 133, 132, 132, 129, 130, 132, 140, 137, 129, 130, 128, 127, 134, 135, 140, 132, 130, 128]"
3,"[86, 87, 86, 86, 86, 87, 91, 93, 92, 89, 88, 88, 92, 94, 91, 90, 90, 87, 90, 93, 88, 87, 86, 85]"
3,"[89, 89, 89, 89, 90, 89, 87, 87, 89, 89, 90, 90, 88, 89, 84, 89, 90, 89, 88, 87, 90, 91, 92, 92]"
3,"[65, 63, 68, 63, 65, 64, 72, 79, 85, 83, 80, 83, 88, 90, 88, 85, 86, 89, 92, 93, 88, 83, 71, 70]"
3,"[36.5, 37.5, 36.5, 37.5, 36.5, 37.5, 36.5, 37.5, 36.5, 37.5, 36.5, 37.5, 36.5, 37.5, 36.5, 37.5, 36.5, 37.5, 36.5, 37.5, 36.5, 37.5, 36.5, 37.5]"
4,"[36.5, 37.5, 36.5, 37.5, 36.5, 37.5, 36.5, 37.5, 36.5, 37.5, 36.5, 37.5, 36.5, 37.5, 36.5, 37.5, 36.5, 37.5, 36.5, 37.5, 36.5, 37.5, 36.5, 37.5]"
4,"[120, 122, 122, 121, 123, 127, 129, 133, 132, 132, 133, 129, 138, 139, 131, 132, 133, 132, 136, 138, 137, 132, 128, 126]"
4,"[88, 83, 88, 83, 88, 83, 88, 83, 88, 83, 88, 83, 88, 83, 88, 83, 88, 83, 88, 83, 88, 83, 90, 83]"
4,"[90, 90, 89, 91, 89, 89, 88, 87, 88, 89, 88, 89, 86, 89, 90, 90, 84, 89, 87, 86, 89, 89, 84, 91]"
4,"[74, 76, 86, 75, 77, 76, 78, 77, 79, 76, 77, 78, 79, 76, 75, 74, 77, 76, 79, 80, 81, 78, 76, 76]"
5,"[142, 141, 142, 141, 140, 144, 149, 151, 152, 149, 148, 147, 148, 150, 147, 144, 143, 145, 149, 152, 149, 143, 142, 140]"
5,"[88, 89, 88, 87, 88, 89, 86, 87, 86, 85, 84, 86, 84, 87, 89, 89, 88, 87, 86, 85, 84, 89, 88, 89]"
5,"[86, 87, 86, 89, 86, 89, 91, 93, 93, 94, 92, 90, 96, 97, 92, 93, 92, 92, 94, 96, 95, 93, 91, 90]"
5,"[36.5, 37.5, 36.5, 37.5, 36.5, 37.5, 36.5, 37.5, 36.5, 37.5, 36.5, 37.5, 36.5, 37.5, 36.5, 37.5, 36.5, 37.5, 36.5, 37.5, 36.5, 37.5, 36.5, 37.5]"
5,"[65, 63, 67, 66, 68, 71, 78, 84, 88, 90, 88, 89, 95, 94, 88, 85, 88, 91, 95, 93, 90, 84, 78, 73]"
```

Figure 4. The measurements sample data set.

3.2. Discussion

As stated above, the focus of this paper is not on the discussion of the actual measures in the PostgreSQL database, neither on the values of the summary statistics inferable from them. Vice versa, the emphasis is on underlining the ways those computations were accomplished and, at the same time, how the output to be returned to the physician looks like. SQL is the tool made available by DBMSs for making computations. Figures 5–7, for example, show the query that returns the summary statistics about SPO2 for patient `p_code = 1`.

```sql
WITH summary_statistics AS (
SELECT
   min(m_value->>'SPO2')::numeric(6,1)  AS minimum_SPO2_last24h,
   MAX(m_value->>'SPO2')::numeric(6,1)  AS MAXIMUM_SPO2_last_24h,
   AVG((m_value->>'SPO2')::numeric(6,1))::numeric(6,1) AS AVG_SPO2_last_24h,
   MAX((m_value->>'SPO2')::numeric(6,1)) - min((m_value->>'SPO2')::numeric(6,1))
                AS range_of_SPO2_last_24h,
   stddev((m_value->>'SPO2')::numeric)::numeric(6,1) AS SPO2StandardDeviation_last_24h,
   (stddev((m_value->>'SPO2')::numeric) /
           AVG((m_value->>'SPO2')::numeric(6,1)))::numeric(6,3) AS  CV_last_24h
FROM  measurement
WHERE p_code = 1),

row_summary_statistics AS (
  SELECT
    1 AS p_code, 'minimum_SPO2_last24h' AS statistic, minimum_SPO2_last24h AS value
  FROM summary_statistics
  UNION
```

Figure 5. The first portion of the SQL query that computes the summary statistics about SPO2.

```sql
  SELECT
  1  AS p_code, 'MAXIMUM_SPO2_last_24h' AS statistic, MAXIMUM_SPO2_last_24h AS value
  FROM summary_statistics
  UNION
  SELECT
  1  AS p_code, 'AVG_SPO2_last_24h' AS statistic, AVG_SPO2_last_24h AS value
  FROM summary_statistics
  UNION
  SELECT
  1  AS p_code, 'range_of_SPO2_last_24h' AS statistic, range_of_SPO2_last_24h AS value
  FROM summary_statistics
  UNION
  SELECT
  1  AS p_code, 'SPO2StandardDeviation_last_24h' AS statistic,
                SPO2StandardDeviation_last_24h  AS value
  FROM summary_statistics
```

Figure 6. The second portion of the SQL query that computes the summary statistics about SPO2.

```sql
 UNION
 SELECT
    1 AS p_code, 'CV_last_24h' AS statistic, CV_last_24h AS value
 FROM summary_statistics )

SELECT *
FROM row_summary_statistics
ORDER BY statistic;
```

Figure 7. The third portion of the SQL query that computes the summary statistics about SPO2.

This query makes a relatively complex computation in a solution that looks simple thanks to the use of the Common Table Expression (CTE) construct. CTEs work as virtual tables (with records and columns), created during the execution of a query, used by the query, and eliminated after query execution. CTEs often act as a bridge to transform the stored data in source tables to the format suitable to the end user.

Tab.1 collects the values of the six statistics taken into account in this study, for patient `p_code = 1`. Those values were computed by running the query `SELECT * FROM ViewOfViews`; the latter is defined in terms of five views (Fig. 8). The exam of the statistics in Tab.1 offers to the physician an overview, over a fixed time interval, of the state of health of the remote patients for which she/he is responsible.

Table 1. The summary statistics for patient `p_code = 1`.

p-code	statistic	temperature	HRate	SPO2	DBP	SBP
1	min	36.4	60.0	86.0	72.0	111.0
	MAX	36.9	78.0	94.0	79.0	129.0
	range	36.9	78.0	94.0	79.0	129.0
	AVG	36.9	78.0	94.0	79.0	129.0
	STD	36.9	78.0	94.0	79.0	129.0
	CV	0.003	0.074	0.024	0.024	0.049

```sql
CREATE VIEW patientSummaryTable (p_code, statistic, value) AS
 SELECT col1 AS p_code, col2 AS statistic, col3 AS value
 FROM spo2_view
UNION ALL
 SELECT col1 AS p_code, col2 AS statistic, col3 AS value
 FROM hrate_view
UNION ALL
 SELECT col1 AS p_code, col2 AS statistic, col3 AS value
 FROM DBP_view
UNION ALL
 SELECT col1 AS p_code, col2 AS statistic, col3 AS value
 FROM SBP_view
UNION ALL
 SELECT col1 AS p_code, col2 AS statistic, col3 AS value
 FROM temp_view;
```

Figure 8. The view that returns the values of the six statistics, for patient `p_code = 1`.

To get the summary statistics about patients, the physician has to connect to the server hosting the PGHD and authenticate himself. To make the access to those data easier, it is helpful develop a WEB application exposing a simple GUI. This step is out of scope of the present short paper.

4. Conclusion

This paper elaborated on the marriage of the IoT and DBMS technologies in the perspective of implementing an effective Long-Term Care service. The SQL statements necessary for implementing the solution are shown. The stakeholders of the study are IT professionals which can customize our solution to their actual needs.

The work-flow of the interaction of the physician with the database comprises two steps:

- first, she/he choices the code of the remote patient to be monitored (let say, `p_code = 1`),
- then, she/he enters the time interval that the query processor has to be taken into account in the computation of the summary statistics of the values of the following vital parameters for the selected patient: temperature, Heart Rate, Oxygen Saturation, Systolic Blood Pressure, and Diastolic Blood Pressure.

At that point, the DBMS makes the computation. Technically, the values of the statistics are inserted into a PostgreSQL temporary table (it is known that temporary tables are automatically dropped at the end of an SQL session).

Before each of the 30 summary statistics in Tab.1 (lets denote the value of the generic one as `ss_value`) is written in the database temporary table, a PL/pgSQL trigger is run. The trigger function that implements the trigger compares `ss_value` with a threshold value for that parameter. Such a value is entered by the physician who is supposed to know how to set it according to the (bio)medical and non-(bio)medical patient characteristics. Each time a potential critical situation of the health status of the patient is identified, the trigger function returns an alert to the physician.

The SQL which implements the alarms is omitted because of the 6-pages limit.

Conflicts of Interest: "The authors declare no conflict of interest."

Sample Availability: All data mentioned in the paper are available from the author.

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