Modeling Telehealth Services with Generalized Nets

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Abstract Generalized Net model of processes, related to tracking the changes in health status (diabetes) of adult patients has been presented. The contemporary state of the art of the telecommunications and navigation technologies allows this model to be extended to the case of active and mobile patient. This requires the inclusion of patient's current location as a new and significant variable of the model. Various opportunities are considered for the retrieval of this information, with a focus on the optimal ones, and a refined Generalized Net model is proposed.

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1 Introduction

Ambient-Assisted Living, telecare, and telehealth belong to the framework of assistive technologies, the aim of which is to secure an independent life at home for elderly and/ or chronically ill people or persons with disabilities as long as possible. In addition, there was in recent years a number of national and international policy initiatives and projects to develop the necessary technologies in pilot projects to test or to support the implementation. In Germany, it is the BMBF/VDE Initiative Ambient-Assisted Living, which significantly contributed to the connection of all relevant social groups. In Great Britain, the Department of Health has developed the whole systems demonstrator program to promote large-scale telecare/telehealth and to carry out the world largest randomized study. In Australia were created an Independent Living Centers as the LifeTech center in Brisbane, in addition to the large areas of assistive technologies, specifically telecare and telehealth. Relevant services were developed and tested [1].

The most effective assistive technology mentioned in research in Australia and United Kingdom is when older people are provided with early intervention, careful assessment, the correct prescription, and home-based follow-up training in how to use assistive technologies. The most effective assistive technologies, identified in research [2, 3] are aids, devices, and equipment to improve quality of life, environmental adaptations to the home, telecare/telehealth, and smart technologies. Although only brief information is given of assistive technology policies and developments in other countries, there is work under way to expand the provision of assistive technologies to older people in a number of countries, including the United States, Japan, China, Spain, and many Scandinavian countries.

One of the main goals of the EU Project MATSIQEL (Models for Aging and Technological Solutions for Improving and Enhancing the Quality of Life (2011–2013), IRSES People Marie Curie Action) is the research on new technologies, used for concepts as Ambient Assisting Living, Telecare or Telehealth, and their contribution for improving the quality of life of older people worldwide. The research field is interdisciplinary. The partners in the project are from different countries and different research areas—Northumbria University in UK (the project coordinator), University of Applied Sciences in Frankfurt, Germany, the Griffith University in Brisbane Australia, die Universidad National Autonoma de Mexico, University Kapstadt in South Africa

The Bulgarian partner is the Institute of Biophysics and Biomedical Engineering at the Bulgarian Academy of Sciences. New knowledge for development of new devices should be developed on the base of Generalized Net approach. Here, we shall show the application of the apparatus of Generalized Nets (GNs, see [4–6]) to assistive technology, namely to telehealth (including the action of a medical doctor) services for diabetes, and the advantages of using such model.

Diabetes mellitus (DM) is a major cause of mortality and morbidity in every country. In 2011, more than 366 million people had DM worldwide. Due to the world's increasingly aging populations, increasingly unhealthy diets, sedentary lifestyles, and obesity, it is estimated that the prevalence of DM will increase to 552 million people by 2030. DM is an intractable condition in which blood glucose levels cannot be regulated normally by the body alone; it has many complications, including cardiovascular diseases, nephropathy, neuropathy, retinopathy, and amputations. The treatment methods include dietary regulation to control blood glucose levels, oral medication, and insulin injection; however, all of these have adverse effects on the patients' quality of life.

Type 1 diabetes, Type 2 diabetes, and gestational diabetes are three main types of diabetes, although there are some other forms of DM, including congenital diabetes, cystic fibrosis-related diabetes, and steroid diabetes, induced by high doses of glucocorticoids. Type 1 diabetes is an autoimmune disease with pancreatic islet beta cell destruction. It is an autoimmune disorder in which the body cannot produce sufficient insulin. Type 2 diabetes, the most prevalent form, results from insulin resistance with an insulin secretary defect. Both Type 1 and Type 2 diabetes are chronic conditions that usually cannot be cured easily. Gestational diabetes is the term used when a woman develops diabetes during pregnancy. Generally, it resolves after delivery, but it may precede development of Type 2 diabetes later in life [7].

Criteria for the diagnosis of diabetes: Fasting glucose: ≥7.0 mmol/l (126 mg/dl) Fasting is defined as no caloric intake for at least 8 h. Symptoms of hyperglycemia and a casual plasma glucose ≥11.1 mmol/l (200 mg/dl). Casual is defined as any time of day without regard to time since last meal. The classic symptoms of hyperglycemia include polyuria, polydipsia, and unexplained weight loss. In conclusion, when the fasting blood glucose is above 7 mmol/l or blood glucose after 2 h after eating is above 11,1 mmol/l the patient has diabetes [8]. In order to have a view on the state of the patient and to have a reaction by a doctor we should monitor the blood glucose. The control of blood glucose levels relies on blood glucose measurement. Diabetic patients, whether Type 1 or Type 2, are encouraged to check their blood glucose levels several times per day; currently, the most common means of checking is using a finger-prick glucose meter. In this way, diabetic patients can obtain a clear picture of their blood glucose levels for therapy optimization and for insulin dosage adjustment for those who need daily injections. Finger-pricking, however, has several disadvantages. Many people dislike using sharp objects and seeing blood, there is a risk of infection, and, over the long term, this practice can result in damage to the finger tissue. Given these realities, the advantages of a noninvasive technology are easily understood. Further, the finger-prick glucose meter is a discrete glucose measurement device that is not practical for continuous monitoring of blood glucose. Some incidences of hyperglycemia or hypoglycemia between measurements may not be recorded. Thus, the resultant monitoring cannot fully represent the blood glucose pattern. Noninvasive glucose measurement eliminates the painful pricking experience, risk of infection, and damage to finger tissue. The noninvasive concept was launched more than 30 years ago. Nevertheless, it can be said that most of the noninvasive technologies are still in their early stages of development. Many noninvasive technologies have been described in the literature, and there is an increasing volume of recent research results.

Table 1 Information regarding noninvasive glucose-monitoring devices

Company (or Device)	Technology	Status
BioSensors Inc.	Bioimpedance spectroscopy	Under development
Freedom Meditech	Fluorescent technology	Awaiting FDA approval
Cnoga Medical	Near-infrared spectroscopy	Awaiting FDA approval
C8 MediSensors	Raman spectroscopy	Investigational device
Positive ID	Chemical sensing in exhaled breath	Under development
EyeSense	Fluorescent technology	R&D phase
Calisto Medical Inc.	Bio-electromagnetic resonance	Under production
Integrity Applications Ltd.	Ultrasonic, conductivity and heat capacity	Clinical trials phase
Grove Instruments	NIR spectroscopy(optical bridge technology)	Clinical trials phase
SCOUT DS, VeraLight Inc.	Fluorescent spectroscopy	Approved

Noninvasive glucose-monitoring technologies

- Bioimpedance spectroscopy
- Electromagnetic sensing
- Fluorescence technology
- Mid-infrared spectroscopy
- Near-infrared spectroscopy
- Optical coherence tomography
- Optical polarimetry
- Raman spectroscopy
- Reverse iontophoresis
- Ultrasound technology

Table 1 shows the most recent developments concerning noninvasive glucose measurement (c.f. [7])

It is important to note that noninvasive monitoring will never be achieved without vigorous scientific and clinical evidence. Many technical issues should be still resolved in order to have a reliable, technically proven glucose measurement.

Further we consider a noninvasive glucose meter as a sensor capable of collecting, storing (to some extent), analyzing the obtained data, and consequently taking the most expected decision. In practice, two types of sensors are considered. The first type are the sensors which are attached to the patient's body. These sensors are looking for biomedical parameters, e.g., ECG signal, SPO2 (Saturation of Peripheral Oxygen). The second-type sensors which are stationary are placed in the rooms to monitor for CO(carbon monoxide) concentration. There are also life sensors which are similar to the first type but work in standby mode and are activated by patient—when event has occurred, e.g., extra beats, the patient pushes event button and the sensors collect the signal. The first and second life sensor types are patient-independent and can work autonomously [9].

For the considered sensor, alarm message is sent to the server and, if necessary, parameter value (or a series of them). The server can send requests to the sensor to confirm the alarm event or the parameter. With these sensors we can have the False positive event. For this reason, the server has to have very smart filter for False positive removal or translate the alarm event to human operator if the case is complicated. This type of sensors can work with a cheap smart module for connecting to the GSM network. Since this network allows more flexibility, the patient is free to go wherever he wants. These sensors can make communication to smart phone by Bluetooth or direct cable communication. Nowadays, the existing GSM network has enough speed and data translation capability via, e.g., network type 3G and 4G too. Also these GSM modules can have a GPS module. This GPS module is necessary in case that the medical center has to localize the person in urgent cases such as earthquake, fires, etc. The smart module can send the GPS coordinates to the rescue center for easy localization of the person or persons. In order to carry out the connection between GSM networks, the sensor should have a GSM module or a smart module. Another requirement to prevent connection break is that the GSM module has to be connected to at least two networks available or a WiFi network connection should be accessible [10].

Further for the purpose of discussion, we will assume that the sensor carrier is equipped with a GPS tracking unit (a device using the Global Positioning System to determine the precise location of a vehicle, person, to which it is attached and to record the position of the asset at regular intervals). The recorded location data can be stored within the tracking unit, or it may be transmitted to a central location data base, or internet-connected computer, using a cellular, radio, or satellite modem embedded in the unit. This allows the asset's location to be displayed against a map backdrop either in real time or when analyzing the track later, using GPS tracking software http://www.liveviewgps.com/. GPS personal tracking devices assist in the care of the elderly and vulnerable. Devices allow users to call for assistance and optionally allow designated carers to locate the user's position, typically within 5 to 10 m. Their use helps promote independent living and social inclusion for the elderly. Devices often incorporate either one-way or two-way voice communication which is activated by pressing a button. Some devices also allow the user to call several phone numbers using preprogrammed speed dial buttons. GPS personal tracking devices are used in several countries to help in monitoring people with early stage of dementia and Alzheimer http://www.eurogps.eu/bg/world-news/tracking/99-gps-tracking-alzheimer.

2 Generalized Net Model

The *GN* model developed on the base of the models from [9] and [10] (see Fig. 1) consists of

- eleven transitions: $Z_1, \ldots, Z_{11}$;
- thirty-one places $l_1, \ldots, l_{31}$;

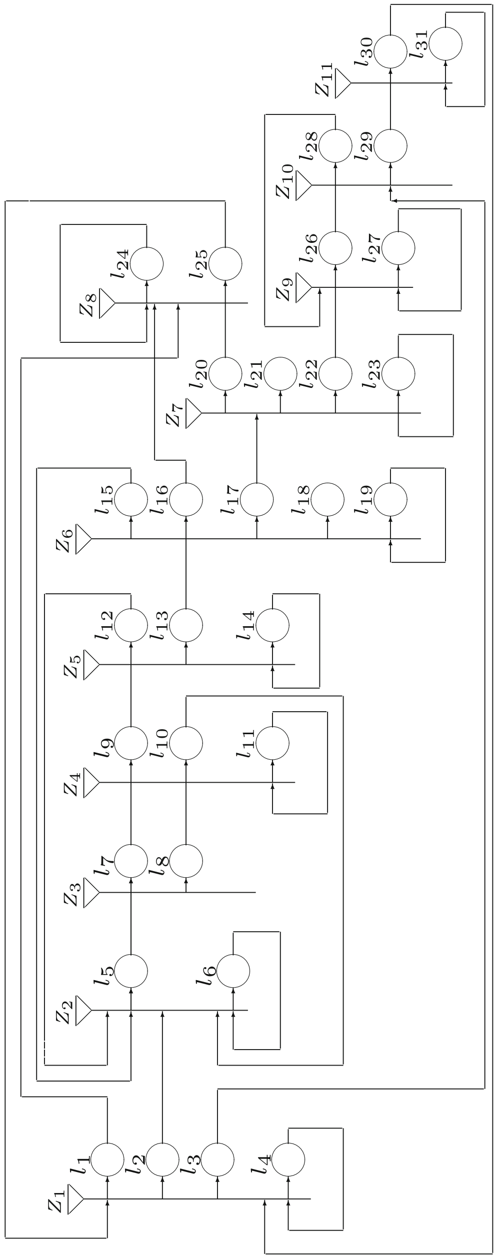

Fig. 1 The generalized net model

- tokens representing the patients, the sensors, criteria for correctness of the signals, history, and previous actions taken, the dispatchers that monitor the signals from the sensors, the medical doctors who examine the patients and the medical specialists who transport the patient to the hospital;

Tokens $\pi_1, \pi_2, \dots, \pi_k$ which represent the patients enter the net in place l_4 with initial characteristic

"patient; name of the patient; current health status"

Tokens $\sigma_1, \dots, \sigma_m$ which represent the sensors enter the net in place l_6 with initial characteristic

"name of the patient; type of sensor"

As an example, we can include in the model the glucose meter which was discussed in the previous section by adding an additional σ-token.

Tokens α and β enter the net in places l_{11} and l_{14} respectively with initial characteristics

"criteria for the correctness of the signals"

Tokens $d_1, \dots, d_n$ enter the net in place l_{19} with initial characteristics

"name of the patient; previously recorded sensor data and respective action taken"

Tokens $\delta_1, \dots, \delta_k$ enter the net in place l_{23} with initial characteristics

"dispatcher; name of the dispatcher; information about all received signals"

Tokens $s_1, \dots, s_l$ enter the net in place l_{27} with initial characteristics

"medical specialist responsible for the transportation of the patient; name of the specialist"

Tokens $\mu_1, \mu_2, \dots, \mu_p$ which represent the medical doctors who examine the patients enter the net in place l_{24} with initial characteristic:

"medical doctor; name of the medical doctor; specialty"

Below is a formal description of the transitions of the net.

$$Z_1 = \langle \{l_4, l_{30}, l_{25}\}, \{l_1, l_2, l_3, l_4\}, \begin{array}{c|cccc} & l_1 & l_2 & l_3 & l_4 \\ \hline l_4 & false & W_{4,2} & W_{4,3} & true \\ l_{25} & true & false & false & false \\ l_{30} & false & false & false & true \end{array} \rangle,$$

where
$W_{4,2}$ = "there is a change in the current patient's status.";
$W_{4,3}$ = "the current patient must be transported to hospital";

When the truth value of the predicate $W_{4,2} = true$ the token π_i representing the i-th patient (here and below $1 \leq i \leq k$) splits into two tokens the original token π_i that continues to stay in place l_4 with the above-mentioned characteristic, and token π_i' that enters place l_2 where it does not obtain new characteristics. When the truth value of the predicate $W_{4,3} = true$ the current π_i token enters place l_3. In place l_1 the tokens obtain the characteristic

"duration of the examination of the patient"

$$Z_2 = \langle \{l_2, l_6, l_{10}, l_{12}, l_{15}\}, \{l_5, l_6\}, \begin{array}{c|cc} & l_5 & l_6 \\ \hline l_2 & false & true \\ l_6 & W_{6,5} & W_{6,6} \\ l_{10} & false & true \\ l_{12} & false & true \\ l_{15} & false & true \end{array} \rangle,$$

where
$W_{6,5}$ = "the sensor detected the patient's body signals";
$W_{6,6} = \neg W_{6,5}$,
where $\neg P$ is the negation of the predicate P.

When the truth value of predicate $W_{6,5} = true$ the corresponding σ token splits into two tokens—the original and a new one that enters place l_5 with characteristic

"signal of the sensor about the current patient"

$$Z_3 = \langle \{l_5\}, \{l_7, l_8\}, \begin{array}{c|cc} & l_7 & l_8 \\ \hline l_5 & W_{5,7} & W_{5,8} \end{array} \rangle,$$

where
$W_{5,7}$ = "the signal comes from a stationary sensor",
$W_{5,8}$ = "the signal comes from a non-stationary sensor",

$$Z_4 = \langle \{l_7, l_8, l_{11}\}, \{l_9, l_{10}, l_{11}\}, \begin{array}{c|ccc} & l_9 & l_{10} & l_{11} \\ \hline l_7 & true & false & false \\ l_8 & W_{8,9} & W_{8,10} & false \\ l_{11} & false & false & true \end{array} \rangle,$$

where
$W_{8,9}$ = "the criterion shows that the signal of the sensor is correct and it must be further evaluated whether a medical doctor's reaction is necessary.",

$W_{8,10}$ = "the criterion shows that the current signal must be confirmed."
When the current σ token enters places l_9 or l_{10} it does not obtain any new characteristics.

$$Z_5 = \langle \{l_9, l_{14}\}, \{l_{12}, l_{13}, l_{14}\}, \begin{array}{c|ccc} & l_{12} & l_{13} & l_{14} \\ \hline l_9 & W_{9,12} & W_{9,13} & false \\ l_{14} & false & false & true \end{array} \rangle,$$

where
$W_{9,12}$ = "the criterion shows that the signal is incorrect."
$W_{9,13}$ = "the criterion shows that the signal is correct."
In place l_{12} the current σ token obtains the characteristic "there is a problem with the sensor." In place l_{13} the current σ token does not obtain any new characteristics.

$$Z_6 = \langle \{l_{13}, l_{19}\}, \{l_{15}, l_{16}, l_{17}, l_{18}, l_{19}\}, \begin{array}{c|ccccc} & l_{15} & l_{16} & l_{17} & l_{18} & l_{19} \\ \hline l_{13} & W_{13,15} & W_{13,16} & W_{13,17} & W_{13,18} & false \\ l_{19} & false & false & false & false & true \end{array} \rangle,$$

where
$W_{13,15}$ = "the history suggests that the signal must be confirmed";
$W_{13,16}$ = "the history suggests that a doctor should visit the patient";
$W_{13,17}$ = "the signal should be examined by dispatcher";
$W_{13,18}$ = "the patient should be sent to hospital"

$$Z_7 = \langle \{l_{17}, l_{23}\}, \{l_{20}, l_{21}, l_{22}, l_{23}\}, \begin{array}{c|cccc} & l_{20} & l_{21} & l_{22} & l_{23} \\ \hline l_{17} & W_{17,20} & W_{17,21} & W_{17,22} & false \\ l_{23} & false & false & false & true \end{array} \rangle,$$

where
$W_{17,20}$ = "a medical doctor should be sent to examine the patient";
$W_{17,21}$ = "no action is necessary";
$W_{17,22}$ = "the patient should be transported to a medical center";
When the truth-value of the predicate $W_{17,20} = true$ the current σ token enters place l_{20} with characteristic

"a decision to visit the patient has been taken"

When the truth-value of the predicate $W_{17,21} = true$ the current σ token enters place l_{21} with characteristic

"a decision to ignore the signal has been taken"

When the truth-value of the predicate $W_{17,22} = true$ the current σ token enters place l_{22} with characteristic

"a decision to transport the patient to a medical center has been taken"

$$Z_8 = \langle \{l_1, l_{16}, l_{20}, l_{24}\}, \{l_{24}, l_{25}\}, \begin{array}{c|cc} & l_{24} & l_{25} \\ \hline l_1 & true & false \\ l_{16} & true & false \\ l_{20} & true & false \\ l_{24} & W_{24,24} & W_{24,25} \end{array} \rangle,$$

where
$W_{24,25} =$ "a medical doctor should be sent to examine the patient",
$W_{24,24} = \neg W_{24,25}$.
In place l_{24} the σ tokens do not obtain new characteristics. When the truth value of the predicate $W_{24,25} = true$ the μ_i token representing the medical doctor who will visit the patient enters place l_{25} with characteristic

"name of the medical doctor who will visit the patient; name of the patient"

$$Z_9 = \langle \{l_{22}, l_{27}, l_{28}\}, \{l_{26}, l_{27}\}, \begin{array}{c|cc} & l_{26} & l_{27} \\ \hline l_{22} & false & true \\ l_{27} & W_{27,26} & W_{27,27} \\ l_{28} & false & true \end{array} \rangle,$$

where
$W_{27,26} =$ "specialists should be sent to transport the patient to the hospital";
$W_{27,27} = \neg W_{27,26}$. In place l_{26} the current token s_i receives the characteristic

"name of the patient that should be transported to the hospital"

In place l_{27} the tokens receive the characteristic

"names of the staff on duty"

$$Z_{10} = \langle \{l_3, l_{26}\}, \{l_{28}, l_{29}\}, \begin{array}{c|cc} & l_{28} & l_{29} \\ \hline l_3 & false & true \\ l_{26} & true & false \end{array} \rangle,$$

In place l_{28} the tokens receive the characteristics

"time for completing the transportation of the patient"

In place l_{29} the tokens receive the characteristics

"condition of the patient upon arrival at the hospital"

$$Z_{11} = \langle \{l_{29}, l_{31}\}, \{l_{30}, l_{31}\}, \begin{array}{c|cc} & l_{30} & l_{31} \\ \hline l_{29} & false & true \\ l_{31} & W_{31,30} & W_{31,31} \end{array} \rangle,$$

where
$W_{31,30}$ = "all medical procedures are completed";
$W_{31,31} = \neg W_{31,30}$
In place l_{30} the tokens receive the characteristics

"condition of the patient upon discharge from hospital"

In place l_{31} the tokens receive the characteristics

"condition of the patient during the procedures"

3 Conclusion

Telecare/telehealth is the remote or enhanced delivery of services to people in their own home by means of telecommunications and computerized systems. Telecare/telehealth ranges from basic community alarm services to more complex interventions involving fall detectors and sensors which monitor a range of physical behavior. The present GN-model describes the indirect (i.e., by life-sensors, glucosemetres) communication between patients in helpless condition and medical doctors from a telecare/telehealth center. It can be used, e.g., for simulation of different situations, related to increasing the number of emergent cases by diabetes mellitus to which the medical doctors/nurses or the person in the response center must react. The GN-model could show the necessary combinations of sensors used for the different patients on the basis of the simulations, we can determine the minimal number of the necessary professionals in the telecare/telehealth center.

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