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Best regards,

Prof. Dr. Özer ÇINAR


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Approach for a Simplified Meshing Network as Monitoring Solution in Farming Applications

Dennis Bakir[1]; Florian Engels[1]; Robin Bakir [1]

Abstract

In this paper an approach for transferring complex and demanding ICT from industrial production to agricultural infrastructure requirements will be presented. This will enable SME farming businesses to tap the full growing potential of their arable land. The overall goal is to increase yields, crop-quality, efficiency of fertilizer and resource deployment with real-time growing-related data.

Core aspect will be a meshed network of single sensing nodes, that monitor growth-relevant parameters on arable fields. The underlying technique has been approved in manufacturing SME that already utilize production data for controlling and optimizing their production processes, flow of material and machining steps via a thorough ICT-system. Therefore, a qualitative and explorative research design was conducted under 70 German SMEs.

Hereof, a frugalization inspired process led to a microcontroller-operated sensor network that is based on a long-range communication and low-power set up. The system uses specific data rates and is able to permanently cover broad monitoring areas. The respective prototype was empirically examined and provides a reasonable solution space that needs to be further elaborated in long-term field studies.

Besides potent companies that can afford to develop, test and run respective systems, as for instance smart- or precision farming, there is a huge gap to small and medium sized enterprises (SME) that are not able to deploy such technology but count for the majority of companies. That provides the impetus for further research on how to utilize the data for a decision support model.

Keywords: smart-farming, condition-based-monitoring, cultivating, measuring, decision

1. INTRODUCTION

Persistent transformation processes in the industry and economy drive technological progress and affect value creation in most businesses and branches. Technological progress acts as an accelerating catalyst in manyfold ways and offers, in result, new procedures of solution [1]. An intelligent and smart control of processes positively affects resource deployment and its efficiency and is pertinent to quality. Thus, data itself and the velocity of information processing advanced to crucial competitive factors for most businesses. Besides potent companies with highly elaborated production facilities that can afford to develop, test and run respective technologies, there is a huge gap to especially SME, that are not able to deploy such complex systems yet. Whereas, speaking of numbers of scale this kind of enterprises has the potential to disseminate such key technologies for a broader range of users.

The pervasion of powerful technologies from prototypal demonstration to a broad and resilient application is already examined in literature and depicted in product life cycle models. It states that new technologies are primarily available to a closed circle of early adopters at typically higher costs [2]. Thus, most enterprises and

[1] *Corresponding author: INNOVATOR_INSTITUT gGmbH, 45481, Muelheim an der Ruhr, Germany. db@innovator-institut.de*

especially SME cannot afford such high-tech applications besides the fact, that there is no sophisticated machine park available, that would allow digitized operations and enhancing efficiency anyway.

In fact, there is already an increasingly dissemination of data driven production solutions in manufacturing companies to be recognized and includes condition-based monitoring solutions for many applications. So, in terms of technical progress, there is both the need to develop new solutions in the first place and facilitate such concepts later for a broader application and market penetration.

Data technology concepts have been adapted to farming needs and brought up so called smart farming technology (SF), that utilizes modern information and communication solutions. After plant breeding and genetic modelling this technique is referred to the third green revolution and considered as the next milestone in bio-economy and agricultural research [4]. It combines information and communication technologies (ICT), the internet of things, sensors and actuators, geo-positioning, big data, drones, robotic etc. to level up resource efficiency in the field of food production. The technology is said to contribute to a secured food supply, too [3].

The concept of SF is, until now, only common in industrialized countries and enables for cultivating vast landscapes. From a farmer´s point of view, the technology provides sufficient data to support decision making and optimize processes that even allow growing on difficult terrain.

In numbers this means there are in total 266.000 farming companies in Germany that produce goods with a value of 58 bil. EUR on total arable land space of about 17 mil. ha [3]. Indeed, more than 90 % of the farmers already make use of assisting technological solutions, whereas this refers to rather low-tec applications and the extend of automatization of mechanical devices.

Regarding this, it requires at the same time further development of the technology itself and carefully selected simplifications in order to ensure applicability along the value chain and price sensitive users. By this, the research contributes to overcome food supply shortage and resource scarcity.

2. MATERIALS AND METHODS

This paper is based on an explorative research design in the first place, focusing on understanding dependencies and market demands of operators in the farming business regarding monitoring technologies for growth relevant tasks. In addition, a literature study complements the observation with current publications and general market trends on solutions for precision and smart farming technology set-ups, that can be applied even with low technological infrastructure and consider the current technology-related challenges in for small farming businesses.

In order to narrow down these results on a specific research field, a complementary qualitative research design was planned. After the explorative phase with several generic talks with companies and customers who supply agriculture farming tools, in total eight guideline-based expert interviews were conducted. The data were evaluated and benchmarked with literature findings, using pairwise comparison on the identified key parameters. This prioritization enabled for a definitive solution space. Besides interview result from German companies, that represent rather developed market players, an additional research journey to Cuba was conducted as part of the explorative phase.

Hence, the work aims to provide a simplified solution space for further design of a sensing and communication technology for agricultural businesses, a suitable starting point needed to be selected. This approach is considered frugalization and was be applied on a surveillance system for growing-related operations. The underlying technique has already been approved in small and medium-sized manufacturing companies, that use relevant production data via a comprehensive and practical ICT-system in order to control and optimize their production processes.

However, a quantitative study to underline the importance of current processes in the farming business is already being planned to test assumptions derived from the solution path. Considering the total population size, i.e. 266.000 farming enterprises, a sound confidence level of 95 %, which equals 5 % error margin, this leads to a sample size of 384 enterprises to be surveyed from now on. Hence, the goal is to analyze cause and effect relationships within this first instance and secondly establish a comprehensive proposal of the described solution, based on actual customer needs.

3. RESULTS AND DISCUSSION

3.1. Results

The field study revealed the very basic requirements of farmers on the infrastructure. Besides proper tools and machinery (both considered as most important) another 70 % states that ICT support is inevitable to deal with increasing calculation tasks.

Generally, the vast majority (93 %) strives for technological assistance but is not capable to operate such complex solutions. The reasons are missing infrastructure (42 %), high investment and running costs (41 %), time (9 %; for implementation and learning) and minor other factors. Especially the tight supply of reasonable systems seems to be the most important impediment. This is true for both, developed (Germany) and less developed (Cuba) countries.

3.2. State of the art

Latest manufacturing technologies apply cyber physical systems that use data as additional resource for process design, steering and decision-making in production facilities. Characteristic feature of such systems are small areas that are monitored by high frequency communication devices with high data-rates. In addition, steady power supply and ambient conditions isolate this certain use case from farming applications, where wide-area production grounds with versatile surrounding conditions are typic.

There are multiple solutions to transfer data between a data link which comes with different characteristics to handle. First, there are different restrictions about the usable frequency on most continents. That means, a multilayer hardware-layout, which is able to exchange different radiofrequency modules without modifying the software, is a prerequisite for international usecases. Common frequencies for European and north- /south American application are 433, 868, 915 MHz and 2,4 or 5 GHz. Due to the limit of physics, a higher frequency is linked to a higher rate of transmission but induces lower coverage. There already exist various concepts to transmit specific data, even via huge distances, i. e. 25 km, and aggregate them in a networked system [5].

Generally speaking, there is a strong correlation between a stable connection over wide areas and the sampling rate (samples per seconds). For instance, agriculture use cases typically require relatively low sampling rates (1/15 min.). Due to a higher path of transmission to a Server/Datahub lower frequencies with a lower bandwidth are deployed.

Typically, it is based on Long Range (LoRa) or a similar narrowband application (see given frequencies before) in different meshed clusters.

Furthermore, there is an additional technology deployed which uses the 4G-IoT-Narrowband. The advantage of this technology is that multiple measurement-tasks can be run at the same time, only requiring 4G-connection. Afterwards, the data will be transmitted to a web-based API, which processes the Data to useful information. Indeed, even with this technology the described dependency between a high reach and small sampling rate of the data still exists.

Along with the second mayor trend in the agricultural business, precision farming (PF), there arises a huge economic potential [6]. Focusing on a precise cultivation, this approach includes especially digital process technology, that will be examined in this paper. The term itself refers to a farming management concept, based on observing, measuring and responding to inter and intra-field variability in crops. It aims at the targeted deployment of growth relevant factors and separates the fields accordingly into identifiable units. In contrast to common manners, the identified areas are not based on property lines or on the expected average yearly crop yield but on their true potential of bringing up plants in an ecological way. Thus, this approach enables farmers to manage their fields based on the spatial variability, such as the availability of nutrients and expected crop yield [7].

To a much greater extent than ever before, plant protection is guided by the pressurized expectation to avoid damage and economic efficiency. The precision farming method involves measures of small-scale soil cultivation, sowing, fertilization, application of pesticides and other operations.

Prerequisite for this technology is an elaborated and mostly expensive IT infrastructure, that can cope with the amount of data and offer the required computing power. Subsequently, certain barriers to entry arise that leave less developed economies and/or farmers behind and moreover interfere the pervasion of a future technology

3.3. Approach

3.3.1. System design

In the following the systematic approach, on how to establish resilient, reasonable ICT-systems to professionalize farming tasks with low infrastructure requirements will be introduced. The solution is inspired by SF technology and offers a straight potential for resource efficient and sustainable farming with a centralized and condition-based cultivation.

It uses the combination of empirical and experience-based knowledge with data-driven process information to support decision making processes about growth-relevant parameters. The aim is to raise agricultural yields in terms of harvest and returns along the value chain by using mostly given resources by taking advantage of sustainable movements.

The solution is thought to be a platform, enabling a linked sensor network over agriculture surfaces. This platform-architecture includes sensor-nodes that enables a continuous monitoring of growth relevant parameters (see Figure 1)

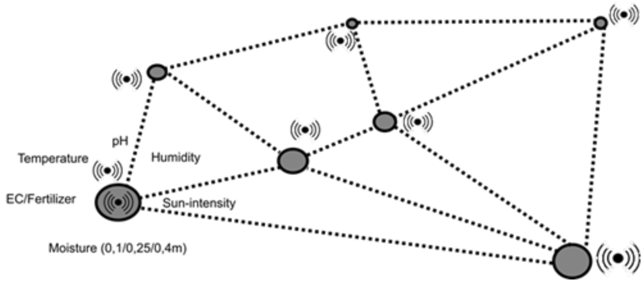

Figure 1: Network with nodes and master hub (left)

3.3.2. Resource monitoring

The solution provides a high-performance low-power measuring set-up for arable land. It is based on a scalable amount of meshed sensing nodes. These can easily be modified and adapted to variable scenarios in order to be implemented for different agricultural applications and are operated with a variable set of input parameters.

Instead of intense capital expenditure for enhancing the technological base and time-consuming efforts for the initial operating as well as maintenance, a smart work-around based on Long Range meshing communication technology is used.

By this, farmers will be provided with a reasonable solution that can be scaled easily. As data will take on a core resource in the set-up, a profound and especially interdisciplinary know-ledge base will be established that will provide an impetus for fostering agricultural business concepts.

By this, practical knowledge and empirical data, as they are already considered as crucial input in manufacturing applications, are transferred to a new application. For different measuring tasks the central hub will be enriched by a scalable CAN-BUS API. This will allow for modification of the used measuring set-up and installed sensors, even in the working environment. As solution, the active transmission of signals of a single entity can be realized via microcontrollers, e.g., type AP2921 by Siemens. Although this type is primarily designed for high-data rates, it provides further advantage regarding scalability (see Figure 2).

This layout can be run with a raspberry-pi infrastructure that enables for an inexpensive and performing approach. Besides, the gathered data of a masterhub can easily be interpreted on the Pi and be forwarded to a

WebSocket API. Especially a WebSocket application promotes the intended usability because it enables for a direct transfer of data to a browser. By means of design, the API can even be directly integrated on the hub. Via a separate control panel, that interface can be used to control external further application, for example data retrieval form a browser.

Regarding the actual sensing tasks, precision will be favoured over resolution. This seems to be appropriate because of the rather raw case of application and a generally lower meaning of resolution on the field. This alignment supports a possibly low cost solution. Nonetheless, both are required for metering tasks, which are not part of the paper.

A distinctive control routine will ensure the long-term applicability of every respective entity in the field. That means, a dynamic battery management will be employed to control sensing intensity depending of the actual power level (i. e. electric potential). With lower power level, the device will prolong its measuring and sending intervals.

According to this, further research will be conducted to determine power limits and respectively timed intervals. In order to even expand on ultra low power operation an extension with photovoltaic powering could be realized, indeed causing additional costs and maintenance efforts.

3.3.3. Communication technology

The generated data-streams get linked via a 433MHz/868MHz/LoRA to a masterhub, which collects all data und send them online to a custom endpoint, like an API, web-dashboard or a cloud-based data storage. The API/dashboard is run by various analysis/graphs, so the user can evaluate the detailed condition of the monitored area. There are various technology of communications existing. If the use case is to create a local network, which even can work offline, a LoRa- or other ISM-Band (free to use) is recommend. If there is need to send the data immediately to a remote web-based server, the IoT-Narrowband on 4G/LTE-base can be used. For a migration of the data by a remote masterhub, LoRa is a data protocol dedicated for low-latency transmission of single data packages.

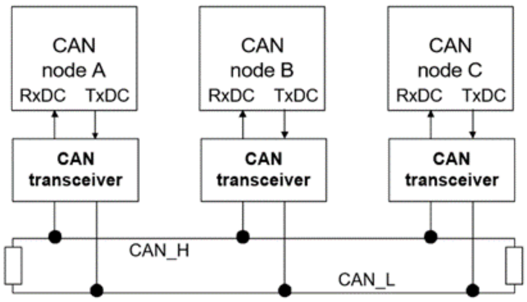

Figure 2. API-layout on the hub to integrate sensors

In contrast to high-frequency production solutions it covers up to 35 km distance between transmitter and receiver. By this

it qualifies especially for the application in agriculture with vast landscapes and partly low internet coverage, such as the 3G standard or even lower.

Typical for measuring tasks in agricultural surrounding lower sampling rates are sufficient. A continuous sampling rate of e.g. 0,02 Hz can easily be operated via LoRa-protocol and prepare the technology to inform even about unexpected conditions and changes with less latency – which by means increasingly happens as a matter of short-term climate changes.

So, the distinctive advantage is its independency from network coverage. In case there is no local internet-connection, the 4G-IoT-Narrowband shall be used to send the data to an online-endpoint, even on outlying geographical areas. This would create a reliable entry point for smart farming even in developing countries with low infrastructure and limited resources to make use of high-end precision farming technologies.

With respect to interoperability and security matters, it seems adequate to use the popular MQTT network protocol that transports massages between devices – in this case a masterhub and several APIs. This technology as well supports the intended meshing for enlarging the potential measuring area.

3.3.4. Security

The security of the collected and processed data gets a high place value. In this concept, all data are heavily secured by a strong AES256 encryption. This kind of encryption seems slightly to be overpowered for agriculture use cases, but due to the frugaliziation of technology, which can be integrated deeply into many industry-processes, it is already developed within the “privacy by design” rule and prepares for potential scale-up operations later on.

Furthermore, the sensor nodes can create a hashvalue considering especially time and potentially geo-information of the collected data, so the receiver (masterhub) can compare the incoming data streams with the hashvalue as a kind of verification.

To prevent a processing of false/corrupted sensor signals, especially in pH, fertilizer or soil moisture measurements, all input-signals have to pass a galvanic isolation. Even though this isolation would result in slightly higher manufacturing costs, it increases the reliability of the system. Furthermore, the galvanic isolation protects the electronic on-chip-circuit against electric discharges.

To detect an incorrect wiring or a damage of the electric circuit between a sensor and the sensor-node, all inputs got a open circuit detection. This means, if a e. g. Negative Temperature Coefficient Thermistor shows an implausible value for the expected temperature-ranges, there must be an incorrect wiring or damage within the sensor itself. The sensor-node detects this error and extends the existing telegram structure with unique errorcodes, so the Graphical User Interface can display a warning sign and push-notifications to the user.

Another security-related task is the prevention of data-loss, which leads to white gaps in the measurement stream. The current approach to prevent this loss is a local, timestamp-based storage on each sensor node. After transmitting data to the masterhub, a checksum is transmitted, so the node and masterhub can identify incorrect transmissions of data. After a transmission is successfully completed, the masterhub saves the data on a timeseries database, like InfluxDB or Prometheus, which is hosted on the desired endpoint like API or cloud. Within the dashboard environment, which is connected to the encrypted timeseries database, the user can create different backup-tasks, like backup to a cloud, local storage or other servers.

For a continuous monitoring of all nodes, each telegram gets added relevant status-information about all connected sensors, battery-level, connection strength and the ratio of successfully vs. unsuccessful transmitted data-packages. So, the user can easily see, which node may need to be checked to prevent more failures.

4. CONCLUSION

High-end SF and PF technologies have the potential for enhancing efficiency. They use digitized arable landmarks that can digitally be managed in order to increase yields and lower resource deployment continuously. For executing such tasks, drones, autonomous harvesters. Accordingly, these can be found most of all are on vast farming areas with already digitized processes and well financed operators. Another prerequisite is an highly elaborated infrastructure with 5G-Networks for a bidirectional data-transmission.

As an effect, this kind of technology requires an already digitized staring point with ICT infrastructure. The full potential of such systems lays in a centralized control entity with high processing power, that can analyze and process the amount of data via artificial intelligence in order to control the machinery on the field. Any bettering and enhancement of such a set up regarding digitization, efficiency and yields require disproportional efforts and especially additional expenditures. Considering this, the technology is rather suitable for already digitized environments and inappropriate for small-scale farms and low-infrastructure landscapes.

In consequence, especially smaller farming-businesses cannot participate in this development and underachieve the growing potential of their arable land. Thus, there is the need for a low-tec application as enabling technology towards fully digitized manufacturing of farming goods.

So, it is evident, that transferring individual sub-technologies, like high performance sensor-meshing, into a more applicable context for regular farmers that could promote the pervasion of the respective technology. In the first place, farmers should gain insight into the actual conditions of their fields by monitoring key performance indicators, such as pH, density, humidity, atmospheric pressure, sun intensity, amount of irrigation water, temperature, fertilizer. This can be realized effectively by implementing meshed sensors across the measuring field. Moreover, large-scale benefits are expected as a result of scale effects.

The presented approach shall provide a basic and thus applicable method for science- and evidence-based farming, complementing to experience based decision. In concrete terms there will be given a solution for monitoring arable space regarding growth-related parameters and derive data-based actions to be taken. With specific data transmission set-ups it will be possible, to easily integrate specific sensor nodes in an agricultural environment to regularly gather at least data on soil, environment and plant conditions. These will be transformed into specific information for machinery and assisting technological entities. The added value will be an enhanced knowledge-base, regarding condition-based cultivating of arable land. By the use of such data, even re-cultivation will be possible, as irrigation water, fertilizer etc. can pointedly be deployed, relating to the actual nutrient concentration in the soil and/or water.

Further advantages, that come along is the predictability of some kinds of pest, which depend on the humidity, sun-intension or amount of fertilizer. The specific advantage will be the maximal scalability of the system by at the same time very low cost of approximately about 200 EUR per node. As a matter of fact, this leads to economic and ecological savings for the farmer resulting from lower expenditures for supplies and working hours.

Ultimately this has positive effects on the economy, too, regarding sustainable and efficient growing of agricultural products by using modern data-driven technologies.

For promoting this approach, further research in terms of empirical assessments will be conducted. This is intended to improve transparency on the actual demand-side, especially about the current state of digitalization, available machines and ICT facilities. In addition, there will be further technical research necessary on the node design and its power supply.

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Evaluation Of Occupational Diseases Of Workers With Medical Imaging Devices In Terms Of Occupational Health And Safety

Aysegul Kocpinar[1], Sukru Kitis[2]

Abstract

With inclusion of hospitals in the category of very dangerous work with the regulation published in 2009, employees working with devices emitting radiation were included in this group. The most natural right of employees is to work in a healthy and safe environment. The main purpose of occupational health is to remove all kinds of negative effects that may occur in the environment and protect health by improving in terms of physical and mental. The riskiest areas in terms of radiation in hospitals are areas where medical imaging devices are located, and the riskiest groups are medical imaging device workers. In this study, it was tried to express what needs to be done in terms of occupational health and safety in these areas and what the employees should do in terms of occupational health and safety.

Keywords: Occupational health and safety in hospitals, radiation, medical imaging devices

1. INTRODUCTION

1.1. Occupational Health and Safety in the Health Sector

According to WHO (World Health Organization), health is expressed not only as absence of disease and disability, but also as a state of complete physical, mental and social well-being. A person's social well-being depends on the health of his/her social life. In societies where work and life security cannot be ensured, possibility of finding a job is difficult, and uneasiness created by income distribution imbalance cannot be eliminated, it is not possible to talk about a person's being full in terms of social condition (Fisek, 1982).

Occupational health generally examines relationships between working life and health. Among the factors that determine employees being healthy, substances and factors in the workplace occupy a very important place (Bilir, 2004). In today's sense, the definition of occupational health according to ILO and WHO; It is "the efforts to maintain and raise the physical, mental and social well-being of people working in all professions". As the basic approach in occupational health and safety, protection and maintenance of health is at the forefront (Bilir, 2006).

The most natural right of employees is to work in a healthy and safe environment. The main purpose of occupational health is to remove all kinds of negative effects that may occur in the environment, and to improve and protect physical and mental health (Ozturk, Babacan, Anahar, 2012). With inclusion of hospitals in the category of very dangerous work with the regulation published in 2009, employees working with devices emitting radiation were included in this group (Tuzuner ve Ozaslan, 2010).

The discovery of X-ray and its use in medicine provided early diagnosis and treatment opportunities for patients. Although it has been used in different fields from the time it was first found to the present, it has a great use in the field of radiology today. It is thought that approximately 2.3 million healthcare workers in the

[1] *Corresponding author: Kutahya Dumlupinar University, Msc Student, aysegulkocpinar@gmail.com*

[2] *Kutahya Dumlupinar University, Simav Technology Faculty, sukru.kitis@dpu.edu.tr*

world are exposed to ionizing radiation from radiation sources during diagnosis and treatment processes. Although there are late effects of radiation, namely, short-term exposures in the long term, its effects on organism may occur years later due to its frequency (Hicsonmez et al., 2015).

1.2. Radiation and Health Sector

The transfer of energy from one point in space to another in the form of electromagnetic waves or particles is called radiation. We live in life with natural and artificial radiation sources that we cannot detect with our sense organs. Radiation is divided into two groups (Figure 1) as ionizing (E > 10 eV) and non-ionizing (E < 10 eV) radiation (Kurtman, 2017. Ege University Handbook, 2021).

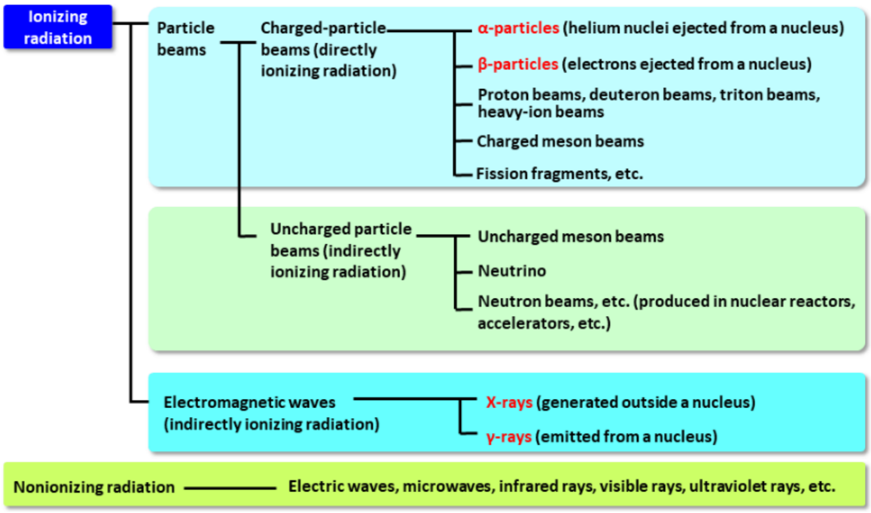

Figure 1. Radiation types (Ege University Handbook, 2014, Ministry of Environment, 2021)

It has long been known that radiation has harmful biological effects on humans. Radiation-related burns, cancer diseases, hereditary disorders and shortening of natural lifespan are the most well-known of these effects. In case of exposure to too much radiation dose, even sudden death can occur. From epidemiological studies, it is understood that there is a significant increase in cancer risk at doses above 100 mSv (Togay, 2002).

Radiobiology is the name of science that studies interactions between living things and ionizing radiation and consequences of these interactions. Changes caused by ionizing radiations in living systems take place in a very short time, but results such as genetic disorders, cancer and death of cells occur over a longer period of time. Radicals such as hydroxyl and hydrogen formed as a result of radiation react with molecules such as DNA and cause radiobiological damage. Since free radicals mediate transmission of radiation to biological molecules, damages are defined as the indirect effect of radiation. Interaction of radiation with biological molecules such as DNA and enzymes and transmission of its energy is called direct effect of radiation. In terms of radiobiology, indirect effect of radiation is more effective than its direct effect and it is accepted that damages occur mostly indirectly (Tuncel, 2008).

Ionizing radiation is used in the medical field for diagnostic and therapeutic purposes. While diagnostic radiography includes conventional/digital x-ray, fluoroscopy, computed tomography, bone densitometry, SPECT, PET, radiotherapy includes brachytherapy, fixed source therapy devices, linear accelerators and proton therapy (Yilmaz, 2021).

Although radiation is generally accepted as destructive and harmful, it is widely used for diagnosis and treatment in the health field. Health sector is one of the working areas where ionizing radiation, especially various imaging tools is used, and its employees are also at risk. Radiologists, radiology unit workers, cardiologists, dentists, urologists, orthopedists, and cardiovascular surgeons are also among the groups at risk.

Nuclear medicine, as a multidisciplinary branch of science, is based on the use of radiation for diagnosis and treatment and widely uses devices such as ultrasonography, magnetic resonance imaging and computed tomography (Yilmaz, 2021).

2. RADIATION PROTECTION AND FUNDAMENTAL PRINCIPLES

Preventing deterministic effects that cause tissue damage and limiting possibilities of stochastic effects to an acceptable level are two main goals of radiation protection (IAEA, 2001).

2.1. Alara (As Low As Reasonably Achievable) Principle

In order to reduce harmful effects of radiation to the lowest level possible, the lowest dose should be given in applications *(Max, 2007)*.

2.2. Limitation Principle

It is a principle determined by ICRP and put into practice upon its recommendation. They are the dose limits determined to prevent applications that exceed upper limits that can be taken other than tolerable dose. These (Max, 2007);

2.2.1. Occupational Exposure

The MMD (Maximum allowable dose) limit determined for employees who are compulsorily exposed to radiation in applications cannot exceed 20 msv for the average of five consecutive years. Employees who exceed these limits leave radiation leave from work, which is a rest month. The permissible dose limit for eye lens cannot exceed 150 msv per year. The annual MMD for skin extremity is 500 msv.

2.2.2. Disenfranchisement

The MMD limit determined for people who are compulsorily exposed to radiation for therapeutic purposes as a result of their illness/injury is below 1msv. It is 15msv per year for eye lens and 50msv per year for skin extremities.

2.2.3. Pregnant Staff

The fetal dose determined by ICRP for pregnant personnel is 5 msv during pregnancy, and radiation dose control should be performed by institution every month during pregnancy. The monthly dose limit is 0.5 msv

2.3 .Dose Limiting System Principles

Determination of dose applications in radiation protection (Zeyrek, 2013):

2.3.1.Necessity of applications

When deciding on radiation applications to individuals or communities, not only scientific views, but also social, economic, and ethical factors should be considered. Negative effects that may occur as a result of radiation applications should be compared with benefit to be obtained.

2.3.2.Optimization:

This principle is also known as the ALARA principle. It is necessary to ensure that the lowest possible doses are applied without ignoring social and economic factors in country.

2.3. 3.Limitation

Doses should be optimized using the ALARA test and individuals should not be exposed to irradiation above the established dose limits.

2.4. Factors determining the effect of radiation

There are four basic principles to be aware of in radiation protection (Sanders et al., 1993);

2.4.1.Distance-Range

It is the most effective and cheapest way of protection from radiation. 75% of the dose taken by healthcare workers is due to time spent less than two meters away during the procedure. As the distance from radiation source decreases, exposure limit increases. Distance is a good shielding tool since ionizing radiation intensities emitted from point sources decrease with square of distance from the source.

2.4.2.Time

Reducing working time with radiation source will also reduce radiation dose exposed. It can be expressed as “Dose = dose intensity x time”.

2.4.3.Barrier-Armoring

The most effective method of protection from external radiation hazards is armoring, and in order to reduce intensity of radiation, a protective barrier with appropriate characteristics should be placed between radiation source and person. Armoring is done by using materials with high protection such as soil, concrete, steel, and lead.

2.4.4.Protection

Specially prepared equipment is used to take personal protection precautions in radiation safety. These equipment are glazed with 0.5mm lead element which does not pass X and Gamma Rays. These equipment available for use; equipment such as lead apron, gonad protector, thyroid protector, lead panel, lead glasses.

2.5. Occupational Health And Safety In Work With Nuclear Radiation

Working with nuclear radiation; Since it is inevitable to use it considering its benefits although harmful effects of radiation exposure are known, it has become imperative to provide the best benefit with the lowest dose to be used. Maximum Allowable Dose (MAD), by the International Commission on Radiological Protection (ICRP); It is defined as the dose of ionizing radiation that is not expected to cause any significant bodily damage and genetic effects in human life (Radiation Safety Regulation Article 2021b).

2.6. Radiation Measurement and Personal Dosimeter Use

Presence and measurements of radiation are made with radiation detectors. The rationale for measuring radiation is based on interaction of radiation and matter. Detector to be used should be chosen according to energy and type of particle. In applications made with radiation, dose measurement should be made in order to ensure safety of employees who are exposed to radiation. Personal dose monitoring device used to determine exposure level is called a dosimeter (figure 2). The process of determining presence and level of ionizing radiation and radioactive contamination is called monitoring. Area and personnel monitoring is done with dosimeters (Donmez, 2017).

Figure 2. Electronic personal dosimeter and detector-germanium (Epsilon, 2021)

2.6.1. Area monitoring

It is mandatory to have a fixed area dosimeter to detect radiation level in areas where ionizing radiation is being worked. Area monitoring dosimeters (figure 3) are used for protection of both employees and other people to ensure adequate protection against radiation (Goksoy, 2021, Radiation Safety Regulation, 2021).

Figure 3. Area Monitoring Dosimeters (Goksoy, 2021)

2.6.2. Personnel monitoring

Personnel monitoring is carried out in order to make measurements to keep personal dose values below the allowable dose limits, to keep records of these measurements, to provide employee with the assurance that their health is protected in terms of radiation exposure, and to provide legal protection to employee who has taken an excessive dose (Karatasli and Ozer, 2017). (Radiation Safety Regulation) Persons working in Working Condition A are required to use a personal dosimeter. Dosimetry service is provided by Agency (TAEA) and organizations deemed appropriate by the Agency, and dosimetric evaluation results are recorded in the central dose registration system.

2.6.3. Protective Equipment

Personal protective equipment: It is all materials, tools, equipment and devices that protect an employee against one or more risks arising from his work, affecting his health and safety, worn, fastened or held by employee, and designed in accordance with this purpose. In order to protect from ionizing radiation, protective equipment suitable for the nature of work done is selected and used by taking into account characteristics of radiation source used in the application and possible exposure situation. (Personal Protective Equipment Regulation, Official Gazette dated 29/11/2006 and numbered 26361). It is known that protective equipment provides a significant reduction in doses when used continuously. Personal protective equipment with CE certificate, which is proper to the relevant standards and protective properties and protection rates against radiation that should be used are documented, should be provided to the employees with occupational health and safety measures to be taken according to the results of the risk assessment. Directions for use should be prepared and applied about which personnel, when and how protective equipment will be used (Karatasli and Ozer, 2017).

2.6.4. Leaded Apron

Appropriate type of protective clothing and lead thickness should be selected according to application. The thickness of the protective clothing to be used while working with X-ray devices should be at least 0.25 mm, and in interventional radiology applications, the lead thickness should be at least 0.5 mm (Figure 4). Radiation stopping rate of lead aprons is approximately 90-95% depending on the energy used in the application. When using lead apron; apron surface should be visually checked for deformation. Periodic compliance tests, including radiography or fluoroscopy tests, should be performed, and recorded. Autoclave and alcohol-containing cleaning materials should not be used for cleaning, it should be kept in special hangers. It should not be placed near heater, it should be kept at a temperature of 10-20 degrees if possible. Lead aprons that have expired should be destroyed by authorized institutions (Keles, 2021).

Figure 4. Leaded Apron (Keles, 2021)

2.6.5. Head and Neck Protectors

Thyroid gland is particularly sensitive to radiation. Radiation exposure is a known risk factor for papillary thyroid cancer. Therefore, a lead neck protector should be worn around the neck in order to protect the thyroid gland. It is important that head/neck protectors are chosen according to the application. Head/neck protectors are used in radiography or fluoroscopy applications. In nuclear medicine applications, they are used injection, milking, distribution process, production facilities and radioactive quality control laboratories, etc. It is used in radiotherapy applications, especially in manual brachytherapy applications (Keles, 2021)

2.6.6. Face and Eye Protectors

Especially those working in operating room and nuclear medicine applications are required to use face and eye protection (figure 5) because they are exposed to radiation for a long time. Due to the fact that the rate of radiation in cataract formation was found to be higher than previously thought as a result of studies conducted in recent years, the dose limit determined for the eye lens has been reduced to 20-50 mSV per year. Radiation protective glasses are made of lead equivalent material (Keles, 2021).

Figure 5. Leaded Glasses (Keles, 2021).

2.6.7. Hand, Arm, Foot and Gonad Protectors

It is important that hand-arm, foot and gonad protectors (fig. 6) are chosen according to application. These protectors are used in radiography or fluoroscopy applications, nuclear medicine applications; injection, milking, distribution process, production facilities and radioactive quality control laboratories, radiotherapy applications, especially manual brachytherapy applications, etc. Leaded gloves should be used to protect hands from radiation. The thickness of the gloves may vary according to the energy of radiation. Leaded gloves should be capable of shielding the entire hand. Gloves should be kept carefully so that they do not break or deform (Keles, 2021).

Figure 6. Leaded Hand, Arm, Foot and Gonad Protectors (Keles, 2021)

2.6.8. Respiratory Protectors

It is appropriate to use P3 masks in accordance with EN 149: 2001 standard in places where solid, liquid or gaseous open radioactive materials are worked, and these radioactive materials are likely to be inhaled by mixing with the air. It may be sufficient to use a face mask in nuclear medicine laboratories, especially in environments where volatile radioactive materials such as I-125 and I-131 are used (Keles, 2021).

2.6.9. Lead Screen and Lead Glass

Especially in studies carried out with mobile devices, the use of mobile lead screens together with personal protective equipment makes a significant contribution to radiation protection. To provide protection against scattered radiation, a lead screen or lead equivalent glass shields (fig. 7) are used between radiation worker and patient. Personnel working in control unit in licensed x-ray laboratories where shooting is performed do not have to wear protective clothing if they are working in section separated by a lead screen or outside the room with a lead equivalent observation window. However, all employees working in controlled area in interventional radiology studies are required to use appropriate protective clothing and a movable lead screen (Keles, 2021).

Figure 7. Leaded Screen, Lead Glass (Keles, 2021)

2.6.10. Other Protective Equipment

Considering characteristics of the radiation source used in the radiation application, working conditions, and possible exposure, appropriate protective (figure 8) equipment (lead cell fume hood, lead injector, lead carrying container, tongs, injectors, forceps, lead balls, etc.) is selected and used (Keles, 2021).

Figure 8. Glovebox, Lead Cell Fume Hood, Lead Carrying Container, Balls, Injector (Keles, 2021)

3. PRECAUTIONS TO BE TAKEN AGAINST RADIATION EXPOSURE

Precautions to be taken in hospitals, dentistry and places with radiation exposure can be stated as follows (Idog, 2021, Guney, 2021, Sargin, 2021, Keles, 2021);

1. Classification of radiation areas should be made in the radiation-containing sections of hospitals. Controlled and supervised areas should be determined. It is mandatory to have radiation warning signs in controlled areas. Employees in these areas are required to use a personal dosimeter.
2. Radioactivity level measurements of radiation areas should be made in accordance with the frequency and methods specified by the Turkish Atomic Energy Agency (TAEA).
3. In order to determine health status of radiation workers and their suitability for their duties, examinations should be made at least once a year before starting work and periodically. In addition, blood counts twice a year, eye and skin examinations once a year are required. Employees in these departments should use appropriate personal protective (lead) clothing and equipment according to the nature of the job.
4. In dentistry applications, dental or jaw films are taken for diagnostic purposes. In institutions that provide oral and dental health services, a separate department is usually established for radiological examinations. However, during the treatment of patient in the practice, dentist may take dental or jaw film himself. In such a case, there is direct exposure to radiation.
5. In ionizing radiation, taking x-ray equipment into clinic causes dentists to be exposed to ionizing radiation.
6. Sources of ionizing radiation used during dental practices are intra-oral x-ray devices and extra-oral imaging devices. Both dentists and auxiliary personnel should protect themselves by standing in a protective environment against radiation.
7. Doors should be kept closed during X-ray use, and X-rays should not be used unnecessarily.
8. When devices emitting radiation are used for diagnosis and treatment, they should be operated with the lowest possible dose.
9. All radioactive materials in health institutions should be protected with an appropriate coating in closed areas.
10. Dose measurements should be made at appropriate times in rooms with radiation and there should be visual warning systems.
11. Radiation used during diagnosis and treatment should not affect anyone other than patient.
12. Only authorized personnel should be allowed to enter areas where radiation sources are located.
13. Areas with sources of radiation should be well defined and properly marked by workers.
14. Healthcare workers should enter areas emitting radiation with appropriate protective clothing and should have a personal dosimeter on them.
15. Routine examinations should be avoided in patients.
16. Examination should not be repeated due to technical errors such as incorrect selection of exposure factors and incorrect position.
17. Importance of time, distance and barrier in radiation control should be well understood and used in practice.
18. As the exposure time increases, the amount of x-rays increases at the same rate. Received radiation is inversely proportional to the square of the distance. Lead or concrete barriers form a front for radiation protection.

19. If there is no standing behind protective barrier, a lead apron must be worn. Dosimeter must be used continuously and worn under lead apron.
20. Patient should not be held during the shoot, metallic fasteners should be used if possible.

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Design And Production Of A Material For Cable Route Protective Layer

***Andac Kilic*[1], *Ilyas Gogebakan*[2], *Oytun Erdemir*[3], *Hasan Celik*[4]**

Abstract

The aim of this work is to design and production of a material as cable route protective layer. The traditional materials that are being used in the current cable routes in Turkey are bricks, pumice concrete and concrete blocks. The traditional materials are prone to breaking during transportation, thus some of the product breaks while being transported to the field. Furthermore, the weight of concrete blocks and bricks make them expensive to transport. Also, these materials are produced in fixed sizes due to manufacturing processes, making them non-optimal for cable route layer dimensions. In this work, we aimed to create a lighter, stronger, optimal size and economic material to be an alternative to the traditional materials. After some research, it has been decided to use thermoplastic materials since they are easy to produce, and Polyvinyl Chloride (PVC) has been chosen for its durability, rigidness and lightweight. Moreover, since the selected material must meet the requirements set by Turkish government agency Turkish Electricity Distribution Co.'s (TEDAS) regulations necessary design adjustments had to be made. PVC processing technique has been chosen as extrusion and a mold has been designed with optimal dimensions for cable routes. After producing the prototype, pressure strength tests have been conducted to ensure that the prototype meets the requirements. As the last step, the prototype has been installed for field tests. In conclusion, an alternative prototype has been designed and produced for cable route protection layers using PVC which reduces costs for such applications.

Keywords: *Cable-route Protection, PVC, Thermoplastic Materials, Extrusion, Underground Powerline, Sustainable Materials*

1. INTRODUCTION

In the field of electricity distribution, ensuring the energy efficiency in the electricity distribution system has the utmost importance. The energy efficiency can be interpreted in many ways such as efficiency of the conductors, preventing the losses in the system or even efficient design of the system and reduce investment and maintenance costs. In terms of reducing the investment and maintenance costs, proper components and appropriate technologies must be used. As an electricity distribution company located in Turkey, we are responsible for building new distribution systems while also maintaining them. With this perspective, the problems and requirements of the distribution systems shows that it is required to follow the scientific developments and. For improving the current state of electricity distribution systems and to catch up with the state of art, we have found an aspect to improve in our system in underground power line structure.

Most of the previously built electricity distribution systems are overhead power line type, however in the current state, while the previous systems are being changed into underground systems, most of the newly built

[1] *Corresponding author: ADM Electricity Co. Adalet Mah., Hasan Gonullu Blv. No:17, 20040 Merkezefendi/Denizli Turkey.* andac.kilic@admelektrik.com.tr

[2] *ADM Electricity Co. Adalet Mah., Hasan Gonullu Blv. No:17, 20040 Merkezefendi/Denizli Turkey.* ilyas.gogebakan@admelektrik.com.tr

[3] *ADM Electricity Co. Adalet Mah., Hasan Gonullu Blv. No:17, 20040 Merkezefendi/Denizli Turkey.* oytun.erdemir@admelektrik.com.tr

[4] *ADM Electricity Co. Adalet Mah., Hasan Gonullu Blv. No:17, 20040 Merkezefendi/Denizli Turkey.* hasan.celik@admelektrik.com.tr

distribution lines are underground type. In the structural design of an underground power line, there are several different layers for protection as stated in [1]. The material that is used for the main protection layer is either bricks, pumice concrete or concrete blocks in Turkey. These materials have many handicaps in the installation process. Due to properties of the materials, up to 20% is lost due to transportation mishaps. Furthermore, since the brick sizes are fixed and the ones used are 40x20x5 cm, to cover a $1m^2$ area 12,5 bricks must be used. This creates a high transportation cost due to volume and weight of the material. A need for an alternative product to be used as the main protection layer has arisen because of these problems.

In Turkey, the governmental regulatory agency which is Turkish Electricity Distribution Co. (TEDAS) is responsible for the regulations and they have published a regulation named "Electricity Distribution Network Energy Cable Installation (Application) Procedures and Principles". The regulation [1] identifies the appropriate materials to be used as the main protection layer for underground power lines. An alternative material must meet the requirements set by [1]. We have researched the literature and examples from other countries to find such a material.

There are several examples which can be seen in [2],[4],[5]. There are several different regulations from different countries such as [3],[6] and various products on the market. However, there were no example from Turkey. Thus, we moved on to selecting a material from existing products. After considering numerous examples such as [2],[4],[5] it has been decided to move on with thermoplastic materials.

2. MATERIALS AND METHODS

After the researching process, thermoplastic materials, and specifically polyvinyl chloride (PVC) has been chosen as the material for main protection layer. The choice has been made because of its ease of production and its various properties such as durability [7], rigidness and lightweight [8]. PVC is already used for wire insulation material for its electrical insulation property. Furthermore, PVC is a more recyclable product compared to the concrete or bricks. Thus, making it a more environmentally friendly material. Since PVC is used as a building material in our case, there are no additive plasticizer in our product. Also, coloring additives can also be used in the production of PVC to add color to the product. In this way, a distinctive color can be selected to classify different underground installations.

2.1. Design of the Prototype

After selecting the material, we have created a design for our prototype. You can see the dimension of our prototype in the Figures 1 and 2.

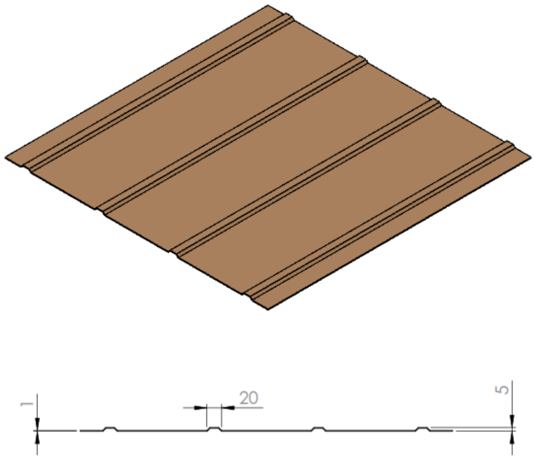

Figure 3. 3D Design of the Product

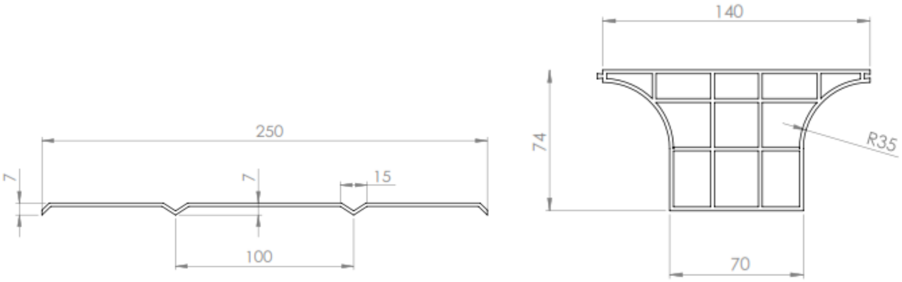

Figure 4. Dimensions of the Prototype

After the prototype has been designed, we have moved on to the production stage. To produce the PVC prototype, there are several options for the production method. We have selected the extrusion method to produce our material.

2.2. Extrusion Method

In extrusion method, the mold of the production line has the utmost importance. Plastic extrusion mold has been produced from stainless steel to produce high quality product and to have a long life. The interior of the mold has been hardened to 50 HRc to have resistance against scratches and wear. The other parts of the mold have been hardened to 30 HRc. To ensure the flow of the molten material, the mold has been produced with an internal heater to keep the temperature same throughout the mold. The produced stainless steel extrusion mold can be seen in Figure 3.

Figure 5. Stainless Steel Mold

After production of the mold, installation of the mold to the extrusion machine has been designed in simulation. The installation process can be seen in Figure 4.

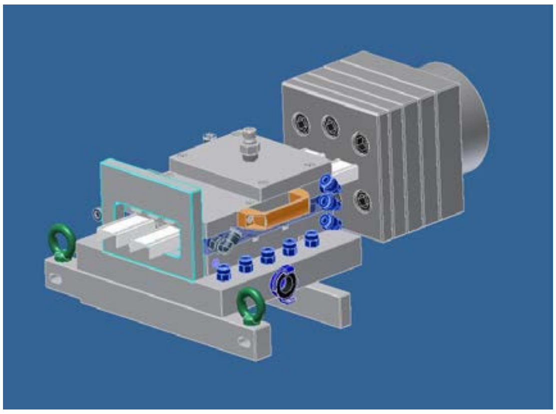

Figure 6. Extrusion Machine with Mold Installed

Then the calibration is done for set temperature and rotation values. After the calibration we have produced our first prototype as can be seen in Figure 5 and 6.

Figure 7. Cleaner material (left) and the First Product (right)

Figure 8. Extruded Material which connects to Calibration Stage

3. RESULTS AND DISCUSSION

According to "Electricity Distribution Network Energy Cable Installation (Application) Procedures and Principles" regulation of TEDAS, the product to be used as the main protection layer must be as least 5mm thick and have an endurance of $5N/mm^2$. However, the prototype we have produced is 2mm thick due to cost efficiency. Despite the 2mm thickness, we have confirmed of endurance of $5N/mm^2$ by doing a pressure strength test on our product. The test and its results can be seen in Figures 7 and 8.

Figure 9. Pressure test

Measurement Method:

Pressure strength test:

PVC material is placed bottom side of the dynamometer and 5N force is applied for 5 minutes. Diameter of pressure apparatus is 15mm.

RESULTS:

Pressure strength test:

As a result PVC material did not damage after test.

Figure 10. Pressure Strength Test Results

After the pressure tests, we have moved on to calculating the cost efficiency of the material. Since we are producing our own product, it can be optimized for the cable route dimensions. Dimensions of the product has been selected as 100x40x2 mm. To calculate the efficiency, a table has been created to compare pumice block versus PVC product transportation properties.

Table 1. Transportation Efficiency Calculation

Material Type	Product Size	Number in a Pallet	A Pallet Weight (kg)	Truck Maximum Carrying Capacity (Kg)	Maximum Number of Pallets to Be Transported in a Truck	Cable Route Length that can be transported by a truck (m)

Pumice Block	50x20	400	2.000	27.000	13	2.600
Thermoplastic Cable Route	100x40	600	1.500	27.000	18	10.800

To understand the Table 1 better, in the city of Izmir in 2014, 174.000 meters of cable route has been constructed. For comparison, to transport a year's worth of pumice block we need 67 trucks, on the other hand to transport a year's worth PVC product we would need only 16 trucks. Furthermore, due to material properties, pumice blocks are more prone to break. Around 20% of the pumice block that has been transported would be broken. By using PVC product, such losses can be prevented.

Afterwards, prototype has been installed on the test field. This has shown that our product can be installed with ease compared to other traditional materials. However, since the regulation does not allow 2mm thickness, products could not be installed in the long term. Because of this reason, product could not be tested in the long term. In Figure 9 and 10, installation of the prototype can be seen.

Figure 11. Prototype Field Tests

Figure 12. Prototype Field Tests

An application to TEDAS has been made for long term use of these products. However, no response has been given to our applications. If a regulation change occurs, the long-term tests can also be conducted.

4. CONCLUSIONS

In conclusion, an alternative underground power line main protection layer has been developed and produced in this work. PVC has been selected because they are easier and faster to deploy and install. Also, this product lowers the transportation costs and losses, and they are easy to color thus differentiation from other cable types would be possible. Furthermore, production process has been successfully completed and a proper mold for extruding PVC has been designed and used. Field tests has been conducted, however since the Turkish regulations does not allow less than 5mm thickness on main protection layer, long-term tests could not be continued.

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Distributed Control for Detecting and Suppressing the Epileptiform Regime in the Populations of Hodgkin-Huxley Neurons

***Sergey Borisenok* [1]**

Abstract

The artificial neural network (ANN) of the Hodgkin-Huxley (HH) neurons demonstrates the variety of regimes for collective spiking and bursting. Particularly, it can cause an epileptiform behavior originated in the hyper-synchronization of the neuron outcomes. In (Borisenok, Catmabacak, Unal, 2018) we proposed the classical model for driving the collective HH neural bursting. Here we discuss the new type of more effective and robust quantum paradigm-based algorithm for detecting and suppressing the epileptiform regime in the small population of Hodgkin-Huxley neurons. Another novelty is the absence of specially designed control elements imbedded to the ANN for the ictal phase detection. The distributed scheme of feedback applies the control signals to the regular HH neurons and makes them to monitor the collective dynamics and drive themselves out of the epileptiform phase. We apply the Kolesnikov target attractor method for the feedback, and discuss the pros and cons of our approach to compare with our classical model of the epileptiform suppression.

Keywords: feedback control, Hodgkin-Huxley neurons, epileptiform dynamics

1. INTRODUCTION

Here we discuss the dynamical system corresponding to the Hodgkin-Huxley (HH) mathematical neuron represented with four ordinary differential equations. Also it contains an one-dimensional control parameter, the electrical current or other similar external signal, stimulating the action potential in the axon. We discuss the similarity of some dynamical regimes of the HH system to quantum bits (in its real ODE representation) in the external field. Both systems can be driven via the free parameters towards the necessary dynamical state (stabilization or tracking goal).

We provide the simple example of the HH-based computational algorithms following the quantum paradigm. It is the Deutsch - Jozsa quantum procedure for a simple searching problem. We define the ‘states’ of HH neuron emulating the pure qubit states, and propose a simple measurement procedure of resting or spiking of the following HH neuron to the searching problem in a single algorithmic cycle.

To demonstrate the possibility of using a multi-dimensional classical system for the realization of quantum algorithms we describe the HH-neuron based adaptation of Deutsch algorithm with Kolesnikov’s target attractor feedback control, and discuss the pros and cons of our approach to compare with our classical model of the epileptiform suppression.

[1]*Corresponding author: Abdullah Gul University, Faculty of Engineering, Department of Electrical and Electronics Engineering, 38080, Kayseri, Turkey. sergey.borisenok@agu.edu.tr*

Bogazici University, Feza Gursey Center for Physics and Mathematics, 34684, Istanbul, Turkey. borisenok@gmail.com

2. THE HODGKIN – HUXLEY NEURONS

The quasi-quantum paradigm based on the quantum computation can be developed and applied to the classical system of Hodgkin − Huxley neuron.

2.1. ODE Model for Hodgkin - Huxley Neuron

The Hodgkin-Huxley differential model has the set of four variables: the output membrane action potential $v(t)$ and three ion channels variables$m(t)$, $n(t)$, $h(t)$ related to the probabilities for the membrane gates to be open or closed [1]:

$$
\begin{aligned}
&C_M \cdot \frac{dv}{dt} = -g_{Na} m^3 h \cdot (v - E_{Na}) - g_K n^4 \cdot (v - E_K) - g_{Cl} \cdot (v - E_{Cl}) + I(t)\ ; \\
&\frac{dm}{dt} = \alpha_m(v) \cdot (1 - m) - \beta_m(v) \cdot m\ ; \\
&\frac{dn}{dt} = \alpha_n(v) \cdot (1 - n) - \beta_n(v) \cdot n\ ; \\
&\frac{dh}{dt} = \alpha_h(v) \cdot (1 - h) - \beta_h(v) \cdot h\ .
\end{aligned} \tag{1}
$$

The membrane variables m, n, h depend on the action potential v via the non-linear functions:

$$
\begin{aligned}
&\alpha_m(v) = \frac{0.1 \cdot (25 - v)}{\exp\left\{\frac{25 - v}{10}\right\} - 1}\ ;\ \beta_m(v) = 4 \cdot \exp\left\{-\frac{v}{18}\right\}\ ; \\
&\alpha_n(v) = \frac{0.01 \cdot (10 - v)}{\exp\left\{\frac{10 - v}{10}\right\} - 1}\ ;\ \beta_n(v) = 0.125 \cdot \exp\left\{-\frac{v}{80}\right\}\ ; \\
&\alpha_h(v) = 0.07 \cdot \exp\left\{-\frac{v}{20}\right\}\ ;\ \beta_h(v) = \frac{1}{\exp\left\{\frac{30 - v}{10}\right\} + 1}\ .
\end{aligned} \tag{2}
$$

The net external current $I(t)$ stimulating the axon is a control parameter in the HH model (1). The set of constantsincludes the potentials E_{Na} (equilibrium potential at which the net flow of *Na* ions is zero), E_K (equilibrium potential at which the net flow of *K* ions is zero), E_{Cl} (equilibrium potential at which leakage is zero) in mV, the membrane capacitance C_M and the conductivities g_{Na} (sodium channel conductivity), g_K (potassium channel conductivity), g_{Cl} (leakage channel conductivity) in mS/cm^2:

$$
\begin{aligned}
&g_{Na} = 120;\ E_{Na} = 115\ ; \\
&g_K = 36;\quad E_K = -12\ ; \\
&g_{Cl} = 0.3;\ E_{Cl} = 10.36.
\end{aligned} \tag{3}
$$

The important property of the dynamical system (1) is the variety of regimes: it can demonstrate resting (the neuron does not show a sufficient activity), spiking (the neuron produces a single spike), bursting (the neuron generates series of spikes).

A particular dynamical regime depends on the input current I. For instance, if the current is below a threshold level, the HH neuron stays in resting; if we overcome the threshold level, it generates a spike.

2.2. Signal Transfer for the Hodgkin - Huxley Neurons

If we combine few HH neurons in a linear chain, the output action potential of the previous one defines the input of the following cell. We use here our gain model for the transfer of the output signal from *k*-th neuron via its synapse towards the dendrite/soma input of the *l*-th neuron [2]:

$$I_l(t) = \alpha \cdot [v_k(t) - v_{\mathrm{rest}}] \; ; \; \alpha = \mathrm{const} > 0, \tag{4}$$

with the phenomenological gain constant α. Here v_{rest} is the reference rest potential in the HH neuron.
We use a simple linear chain of two HH neurons. The first cell plays a role of the computational element, while the second one works as a measuring element. For that we define the threshold (tr) level:

$$I_{\mathrm{tr}} = \alpha \cdot (v_{\mathrm{tr}} - v_{\mathrm{rest}}) \; . \tag{5}$$

Now the output of the first neuron stimulates the particular regime of the second measuring element. If the first HH neuron produces the acting potential below the threshold level v_{tr}, the second neuron does not spike. If the output action potential of the first neuron *v* overcomes slightly the threshold level, the second one produces a single spike.

3. EMULATION OF DEUTSCH ALGORITHM WITH THE PAIR OF HODGKIN - HUXLEY NEURONS

3.1. Deutsch Algorithm

To give an example of a quantum algorithm, let's chose the simple searching problem. Suppose that we get a function *f* mapping $\{0,1\}^n$ into $\{0,1\}$. The constrain on the function gives us only two options: or the function is a constant: $f(x) = 0$ for all *x* from $\{0,1\}^n$ or $f(x) = 1$ all *x* from $\{0,1\}^n$, or it is balanced: the number of inputs 0 for the mapping is equal to the number of inputs 1. We must check if the given function *f* is a constant.

To do it for the classical approach we need $2^{n-1} - 1$ evaluations. Quantum algorithms, from another hand, can perform it much faster.

The basic solution to this searching problem has been proposed by Deutsch in 1985 and generalized in 1992 in the form of the Deutsch – Jozsa algorithm for an arbitrary positive integer *n* [3].

The circuit for the Deutsch – Jozsa algorithm is given in Fig.1. It contains three single-qubit Hadamard gates, one two-qubit gate for the function *f* and one measurement operation. The symbol $\oplus$ stands here for the addition mod 2.

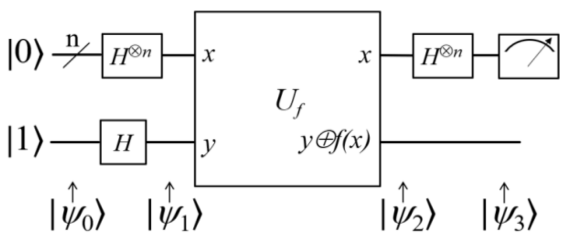

Figure 1. The quantum circuit for the Deutsch - Jozsa algorithm; based on [4].

For simplicity we will focus here on the case $n = 1$. Then the result of the measurement is equal to:

$$\left|\text{output}\right\rangle = \frac{1}{2}\left[(1+(-1)^{f(0)\oplus f(1)})\left|0\right\rangle + (1-(-1)^{f(0)\oplus f(1)})\left|1\right\rangle\right] . \tag{6}$$

Eq.(6) solves the problem of searching. Indeed, if $f(0)\oplus f(1)=0$, then the output is $\left|0\right\rangle$, and the function *f* is constant. If $f(0)\oplus f(1)=1$, then the output is $\left|1\right\rangle$, and the function *f* is balanced. Due to the so-called quantum phase kick-back effect in the algorithm we need only a single measurement to distinguish between those two cases.

The same is valid for the case of *n* bits. If all *n* measurement results are $\left|0\right\rangle$, we conclude that the function was constant. Otherwise, if at least one of the measurement outcomes is $\left|1\right\rangle$, we conclude that the function was balanced.

3.2. 'Quantum States' of Hodgkin - Huxley Neurons

To imitate the Deutsch algorithm, let's define the 'pure quantum states' for the HH neuron: the resting $\left|0\right\rangle$ and the single spiking $\left|1\right\rangle$:

$$\begin{aligned} \left|0\right\rangle &= 0\cdot I_{\text{tr}}\,; \\ \left|1\right\rangle &= 1\cdot I_{\text{tr}}\,, \end{aligned} \tag{7}$$

which corresponds to the action potentials:

$$\begin{aligned} v_{\left|0\right\rangle} &= v_{\text{rest}} + \frac{0\cdot I_{\text{tr}}}{\alpha} = v_{\text{rest}}\,; \\ v_{\left|1\right\rangle} &= v_{\text{rest}} + \frac{1\cdot I_{\text{tr}}}{\alpha} = v_{\text{rest}} + \frac{I_{\text{tr}}}{\alpha}\,. \end{aligned} \tag{8}$$

To unify both cases, let's define the goal potential via the CNOT logical operator over the function *f*:

$$v_{*} = v_{\text{rest}} + \text{CNOT}\{f(0), f(1)\}\cdot\frac{I_{\text{tr}}}{\alpha}\,. \tag{9}$$

The symbol * stands here for the potential *v* (the output of the first neuron) which should be the goal of our control signal *I* in (1).

Our network emulating the quantum algorithms consists of two sequent HH neurons (see Fig.2). The first neuron contains the information about the function ***f***; and is driven by one of the mentioned control algorithms towards the goal action potential (9). The resulting potential of the first neuron with the dendrite/soma model enters the second neuron, which plays a role of the measuring element.

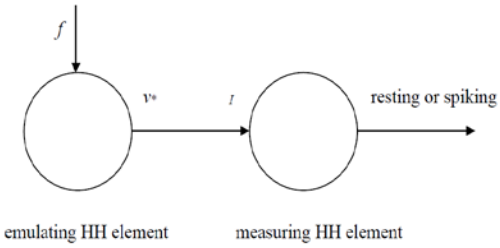

Figure 2. The elementary linear chain of two Hodgkin − Huxley neurons emulating the Deutsch – Jozsa algorithm.

Now suppose that we are able to drive the first neuron towards the goal potential (9). Then it will stimulate the second measuring element with two different options: the second neuron will stay in rest or will generate a single spike. Just based on that we can conclude if the function *f* is constant or not:

$$\begin{aligned} &\text{If } f(0)=f(1), \text{ then } v_* = v_{\text{rest}} = v_{|0\rangle}, \text{ and } f \text{ is constant.} \\ &\text{If } f(0)\neq f(1), \text{ then } v_* = v_{\text{rest}} + \frac{I_{\text{tr}}}{\alpha} = v_{|1\rangle}, \text{ and } f \text{ is balanced.} \end{aligned} \qquad (10)$$

In (10) we got the complete HH analog of the Deutsch algorithm.

3.3. Target Attractor Feedback

The last task is to provide the necessary output (9) of the first neuron. To do it, we can apply different control algorithms based on the gradient approaches [5] or, alternatively, on the construction in the system target attractors, in the manner of 'synergetic' Kolesnikov's algorithm [6].
Here we follow Kolesnikov's approach. To do that, let's define the target function:

$$\psi(t) = v(t) - v_*(t)\ . \qquad (11)$$

Minimazing the magnitude of (13) we drive our system towards the target potential (11). The control equation follows the method [6]:

$$T\frac{d\psi(t)}{dt} = -\psi(t)\ . \qquad (12)$$

The positive constant *T* defines the typical time scale of the target attractor achivement.
Eq.(12) provides the exponentially convergent dynamics of the trajectories to the neighborhood of the target attractor (11) in the phase space.
Then the control signal*I*in the first HH neuron is restored from the substitution of (11)-(12) into the first equation of the system (4). It becomes:

$$\begin{aligned} I_{\text{TA}} &= C_M \cdot \left[\frac{dv_*}{dt} - \frac{1}{T}(v - v_*)\right] + g_{Na} m^3 h \cdot (v - E_{Na}) + \\ &+ g_K n^4 \cdot (v - E_K) + g_{Cl} \cdot (v - E_{Cl})\ . \end{aligned} \qquad (13)$$

The achievability of the goal for an arbitrary stabilization / tracking via target attractor feedback has been proved in [7].

4. DITRIBUTED CONTROL APPROACH

Here we follow the novel control algorithm, and in the place of a fixed pair of the inhibitor control elements, like on Fig.2, we use the randomly chosen cell from ANN as a temporal control element for a limited time interval. Then we pick up another neuron as a control element, and repeat this procedure many times. It allows us to use different existing feedback links between the neurons, and do not apply the same control field simultaneously for the whole ANN.

4.1. Detection of the Epileptiform Regime

Let's first introduce the binary random number generator RND{0,1} generating the integers 0 or 1 with completely equal probabilities. Then let's define the spiking function for the *n*-th neuron as:

$$S_n = \begin{cases} 0, \text{ if } v_n = v_{\text{rest}} \ ; \\ 1, \text{ if } v_n > v_{\text{rest}} \ . \end{cases} \tag{14}$$

Thus, (13) is non-zero for the spiking state, and it is equal to 0 for the resting.

After that, the definition of the function *f* is based on (14):

$$f = \frac{1}{2}\left[1 + (-1)^{\prod_n S_n}\right] \cdot \text{RND}\{0,1\} \ . \tag{15}$$

To use the newly defined function (15) for detecting the hyper-synchronization let's choose arbitrarily the action potentials of some *n* neurons to form the function *f*. We are interested only in the detection of hyper-synchronization, when the product:

$$\prod_n S_n = 1. \tag{16}$$

In the absence of hyper-synchronization, the product (16) is equal to 0. One can easily check that the definition (14)-(15) corresponds to two cases of *f*: it is either always 0 (constant), or the output consists of equal numbers of '0's and '1's (balanced). Thus, two possible cases are:

- **Epileptiform regime:** $f = 0$ always; the function is constant.
- **Regular regime:** $f = 0$ and $f = 1$ in the equal number of cases, i.e. the function is balanced.

The classical analog of the quantum searching algorithm serves for the classification of the ANN dynamical regimes.

4.2. Finalization of the Distributed Control Algorithm

The final form of the detecting and suppressing algorithm is presented in Figure 3. For the purpose of control the *k*-th HH control neuron *k*[C] is randomly chosen from the population of *n* neurons, and this choice is dynamically changing in time. The numbers from 1 to *n* (apart from k) denote the "regular" HH neurons from the ANN.

The control element triggers detects the epileptiform regime from the signals coming from its companions and triggers the feedback control loops T towards the initial set of HH neurons to suppress the hyper-synchronized dynamics in the form described in details in [8, 9], particularly, as the target attractor algorithm (13).

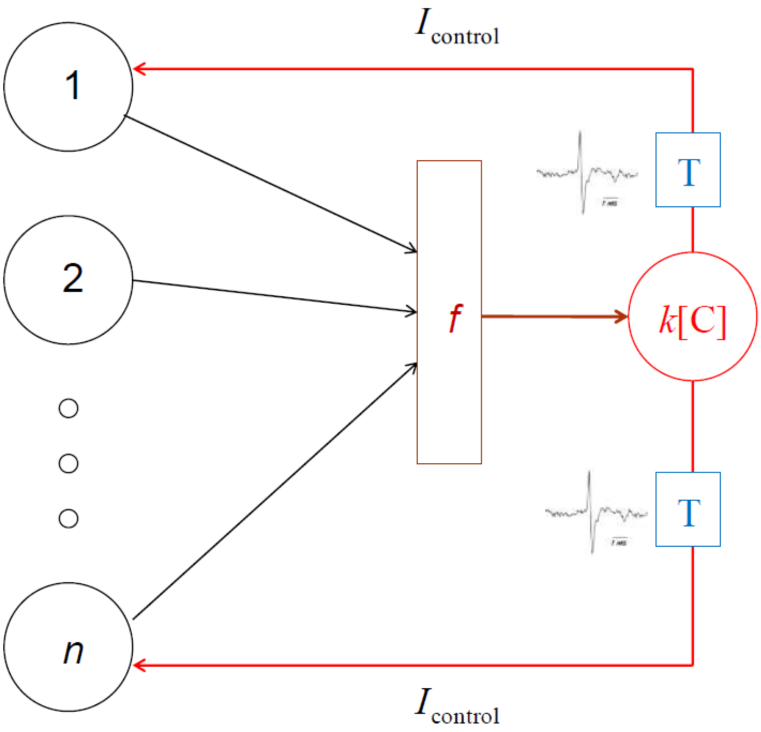

Figure 3. Distributed control algorithm for detecting and suppressing epileptiform dynamics.

Thus, the algorithm in Fig.3 consists of the following steps:

- Form the function *f* over the action potentials of arbitrary numbers of *n* neurons in the population.
- Make the Deutch-type measurement of the function *f* with the pair of control neurons.
- If the function *f* is balanced, there is a normal regime in the population dynamics.
- If the function *f* is constant, there is an epileptiform regime in the population dynamics.
- If the epileptiform regime is detected, the temporal control neuron *k*[C] triggers the feedback suppressing control signal via the triggering feedback loop T to the neurons of the population.

5. CONCLUSIONS

The classical 4d HH system is capable to imitate the effects similar to the Deutch – Josza quantum algorithm.

A randomly chosen HH neuron could be used to detect the ictal phase of the epileptiform regime in the small population of other HH neurons.

The distributed control algorithm of the detection works more efficient to compare with the classical detection algorithms.

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Modeling Optogenetic Control over Epileptiform Activity

Sergey Borisenok [1]

Abstract

Lastyears the genetic engineering methods are applied to excite or inhibit single neurons and their populations via light-sensitive channels with different optical devices. Optogenetics allows neurons to be controlled with millisecond pulses through the light-driven activation or inactivation of the light-gated ion channels such as Channelrhodopsin-2 (ChR2) or pumps such as Halorhodopsin. To study the optogenetic control we use here the 'four state' model of ChR2 channels (Grossman, et al., 2011) with the stimulation applied to the small-scale depolarizing excitatory population of cortical neurons. We develop an algorithm for the Fradkov's speed gradient feedback to drive the collective bursting of the neural population and discuss pros and cons of our model to compare with alternative approaches.

Keywords: optogenetics, epileptiform activity, ChR2 channels, speed gradient feedback

1. INTRODUCTION

Last decade the genetic engineering methods have been applied to excite or inhibit single neurons and their populations via light-sensitive channels with different optical devices.

Optogenetics provides an alternative to electrical stimulation to manipulate membrane voltage, and trigger or modify action potentials in excitable cells [1]. It is superior to classical activation by microelectrodes. The reason for this is due to its high temporal and spatial resolution. Optical stimulation can be achieved by using caged compounds, e.g. caged ATP, caged Glutamate, whereby the substrates for depolarizing ion channels are delivered to membranes and activated by pulses of UV-light to the chemical photolabile cage in the micro- and millisecond time scale.

Optogenetics allows neurons to be controlled with millisecond pulses through the light-driven activation or inactivation of the light-gated ion channels such as Channelrhodopsin-2 (ChR2) or pumps such as Halorhodopsin.

Optogenetics has many applications, for instance, it allows to control functions of neural cells in epilepsy, depression, and tumors of the central nervous system [2]. Optogenetic data can be very useful for reconstructing dynamical models of brain dynamics [3] and for imaging and manipulating brain networks [4]. Together with electrophysiological data, it provides the self-assembled multifunctional neural probes as a powerful tool for investigating causal relationships between neural circuit activity and function [5].

Here we discuss the feedback speed gradient algorithm-based model for control over the membrane conductance in the frame of the Grossman-Nikolic-Toumazou-Degenaar ordinary differential system.

[1] *Corresponding author: Abdullah Gul University, Faculty of Engineering, Department of Electrical and Electronics Engineering, 38080, Kayseri, Turkey. sergey.borisenok@agu.edu.tr*

Bogazici University, Feza Gursey Center for Physics and Mathematics, 34684, Istanbul, Turkey. borisenok@gmail.com

2. CONTROL MODEL FOR OPTOGENETICS

As a basic approach for control algorithms for optogenetics, we chose here the Grossman-Nikolic-Toumazou-Degenaar (GNTD) model [6] for the response of channelrhodopsin-2 (ChR2) expressing neurons to the light stimulation using various types of ChR2 mutants which follows the research [7, 8].

2.1. Grossman-Nikolic-Toumazou-Degenaar Model

The GNTD model describes two open ($O1$ and $O2$) and two closed ($C1$ and $C2$) functional states, which do not necessarily represent the actual energy states of ChR2 [6], see Fig.1.

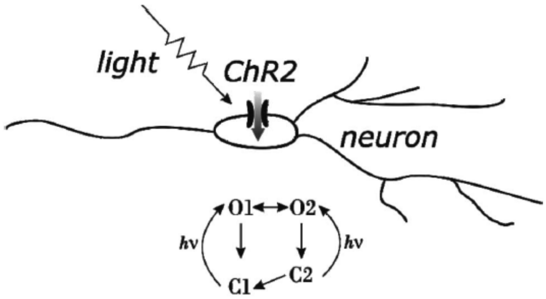

Figure 1.The scheme for the interaction of ChR2 expressing neuron with the stimulating light [6].

ChR2 can be photo-excited from its $C1$ dark-adapted closed state to any open state. From an excited state $O1$, ChR2 either decays back to $C1$ or converts into a different open state $O2$. The state $O2$ is less conductive but more stable in comparison to $O1$. The transition from $O1$ to $O2$ can be both thermal and pulsed light stimuli into ChR2 current. Then from the open state $O2$, ChR2 either decays to aclose state $C2$ or converts back to $O1$, again by thermal or light excitation. From the state $C2$, ChR2 can be photo-excited back to $O2$ or slowly converted (only thermally) to $C1$.

The total number N of ChR2s in a cell section is constant:

$$N_{C1} + N_{C2} + N_{O1} + N_{O2} = N = \text{const}. \tag{1}$$

The population dynamics of these states can be described as the system of the following three differential equations:

$$\begin{aligned} \frac{dN_{O1}}{dt} &= K_{a1}N_{C1} - (K_{d1} + e_{12})N_{O1} + e_{21}N_{O2}; \\ \frac{dN_{O2}}{dt} &= K_{a2}N_{C2} + e_{12}N_{O1} - (K_{d2} + e_{21})N_{O2}; \\ \frac{dN_{C2}}{dt} &= K_{d2}N_{O2} - (K_{a2} + K_r)N_{C2}. \end{aligned} \tag{2}$$

Here the parameters K_{d1} and K_{d2} are the closing rates $O1 \rightarrow C1$ and $O2 \rightarrow C2$, respectively; K_r is the thermal recovery rate $C2 \rightarrow C1$. The values e_{12} and e_{21} are the rates of transition between $O1$ to $O2$ and vice versa. The parameters K_{a1} and K_{a2} are the activation rates $C1 \rightarrow O1$ and $C2 \rightarrow O2$, respectively.

The set of control parameters in the model (2) is defined via the photon flux $\varphi(t)$ per one ChR2 as [6]:

$$K_{ai} = \varepsilon_i \varphi(t);\ i = 1,2, \tag{3}$$

where ε_i is the quantum efficiency in the state C_i (where i= 1, 2).

The total conductance G_{ChR} of a neural section due to ChR2 is given by:

$$G_{\text{ChR}} = (g_{O1}N_{O1} + g_{O2}N_{O2}) \cdot \frac{1 - \exp\{-U / U_0\}}{U / U_1}, \tag{4}$$

where g_{O1} and $g_{O2}$are the conductance of the open states $O1$and $O2$, respectively. Eq.(4) considers the dependence of ChR2 conductance on the absolute trans-membrane potential U, while U_0 and U_1 are empirical constants.

The response of the n-th section of a cell to the change in membrane conductance can bethen described by the following partial differential equation:

$$C\frac{\partial V_n}{\partial t} = -[I^n_{\text{ionic}} + G^n_{\text{ChR}}(\varphi, U)U_n + \gamma^n_{n-1}(V_n - V_{n-1}) + \gamma^n_{n+1}(V_n - V_{n+1})]\ . \tag{5}$$

Here, I_{ionic} denotes the current through the native ion channels, C is the cell section capacitance, and V is the membrane potential relative to rest potential V_{rest} ($U = V + V_{\text{rest}}$; $V_{\text{rest}} = -70$ mV). The parameters γ_n and γ_{n-1} are the conductances between the two neighboring compartments.

The set of the GNTD model constant parameters is given in Table 1. For our numerical simulations, we followed [6] for the following numerical parameter set. The conductances of the open states g_{O1} and g_{O2} are chosen according to [8]. All inverse time scales, including the constant Γ, are taken in ms^{-1}, the conductances – in nS.

Table 1.Set of the GNTD model constant parameters

Parameter	Value	Unit
ε_1	0.5	ms^{-1}
ε_2	0.12	ms^{-1}
K_{d1}	0.1	ms^{-1}
K_{d2}	0.05	ms^{-1}
K_r	0.0003	ms^{-1}
e_{12}	0.011	ms^{-1}
e_{21}	0.008	ms^{-1}
g_{O1}	20	nS
g_{O2}	10	nS
U_0	40	mV
U_1	15	mV

The model (5) assumes that the extracellular potential that is produced by the certain neuron'sown activity is negligible. Thus, the intracellular potential is setequal to the trans-membrane potential.

2.2. *Control Algorithm for the Membrane Conductance*

To control the response of the n-th section of a cell to the change in membrane conductance (5), one needs to handle the total conductance G_{ChR} (4) of a neural section due to ChR2, including the factor

$$g = g_{O1}N_{O1} + g_{O2}N_{O2}\,. \tag{6}$$

For the purpose of stabilization of (6) at the certain target level:

$$g_* = g_{O1}N_{O1*} + g_{O2}N_{O2*}, \tag{7}$$

we consider here the feedback speed gradient algorithm [9]. Let's define the target non-negative function:

$$G = \frac{1}{2}(g - g_*)^2 \, . \tag{8}$$

Minimization of function (8) corresponds to the achievement of the control goal (7). This goal is provided by the gradient ∇_φ in the space of the control parameter (3):

$$\varphi(t) = -\Gamma \nabla_\varphi \left(\frac{dG}{dt} \right) = -\Gamma \frac{\partial}{\partial \varphi} \left(\frac{dG}{dt} \right) \, . \tag{9}$$

Here Γ is a positive constant with the dimension of the inverse time. The control signal in (3) is one-dimensional; therefore the gradient in (9) is reduced to the partial derivative.

By the application of (9) to the target function (7)-(8):

$$\frac{dG}{dT} = (g - g_*) \cdot \left(g_{O1} \frac{dN_{O1}}{dt} + g_{O2} \frac{dN_{O2}}{dt} \right) , \tag{10}$$

and by the substitution (2) into RHS(10), one obtains the control signal in the form:

$$\begin{aligned} \varphi = -\Gamma \cdot \left[g_{01}(N_{O1} - N_{O1*}) + g_{O2}(N_{O2} - N_{O2*}) \right] \times \\ \times \left[g_{O1}\varepsilon_1 (N - N_{O1} - N_{O2} - N_{C2}) + g_{O2}\varepsilon_2 N_{C2} \right] . \end{aligned} \tag{11}$$

We considered in (11) the property (1) for N_{C1}.

2.3. Simplified Model for the Optogenetically Controlled Neuron

The simplified model for the neuron with the notation (6) can be written in the form:

$$C \frac{\partial V(t)}{\partial t} = -I_{\text{ionic}}(V(t)) - gU_1 \cdot \left(1 - \exp\left\{ -\frac{[V(t) - V_{\text{rest}}]}{U_0} \right\} \right) . \tag{12}$$

If $I_{\text{ionic}} = 0$, and $V(0) = V_{\text{rest}}$ as $t = 0$, the solution to (12) is given by:

$$V(t) - V_{\text{rest}} = -\frac{gU_1}{C}(t + A) + U_0 \ln \left[\exp\left\{ \frac{gU_1}{CU_0} \cdot (t + A) \right\} - 1 \right] \, . \tag{13}$$

Here A is a time-dimension constant. The plot for the dimensionless shape $u(\tau)$ of (13) is given in Fig.2.

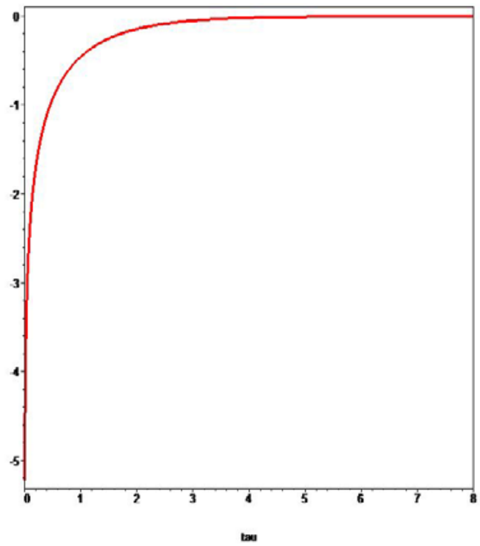

Figure 2. The dimensionless shape u(τ) of Eq.(13).

On Fig.2 we used the notations:

$$u = \frac{V(t) - V_{\text{rest}}}{U_0}\ ;\quad \tau = \frac{gU_1(t - t_0)}{CU_0}\ , \tag{14}$$

Thus, by (13) the control over the function *f* from (6) means the control over the shape of the potential *V*(*t*).

3. CONTROL OVER EPILEPTIFORM DYNAMICS

3.1. Phase I: Detection of the Epilemtiform Dynamics

We follow here our approach [10,11] for the pair inhibitor HH neuron controlling the hyper-synchronization in the small ANN. Let RND{0,1} by '0' or '1' binary random number generator.

We define the spiking function for the *n*-th neuron:

$$S_n = \begin{cases} 0, \text{ if } \ v_n = v_{\text{rest}}\ ; \\ 1, \text{ if } \ v_n > v_{\text{rest}}\ , \end{cases} \tag{15}$$

and, based on (15), the function *f*:

$$f = \frac{1}{2}\left[1 + (-1)^{\prod_n S_n}\right] \cdot \text{RND}\{0,1\}\ . \tag{16}$$

Let's chose now the action potentials of some *n* neurons to form the function *f*. The inhibitor control pair of HH neurons performs the Deutch – Josza algorithm for the function *f* checks whether the following equality is correct:

$$\prod_n S_n = 1\ . \tag{17}$$

Eq.(17) is correct only if there is an epileptiform hyper-synchronization. Thus, for the epileptiform regime: $f = 0$ always; and the function is constant. For the regular regime: $f = 0$ and $f = 1$ in the equal number of cases, i.e. the function is balanced.

3.2. Phase II: Suppression for the Epileptiform Regime

Based on the set of HH neurons enumerated from 1 to n, the function f will be defined as (16). Then the information about this function is treated by the pair of the control HH neurons: e (the HH neuron emulating the quantum algorithm) and m (the measuring HH neuron), see Fig. 3.

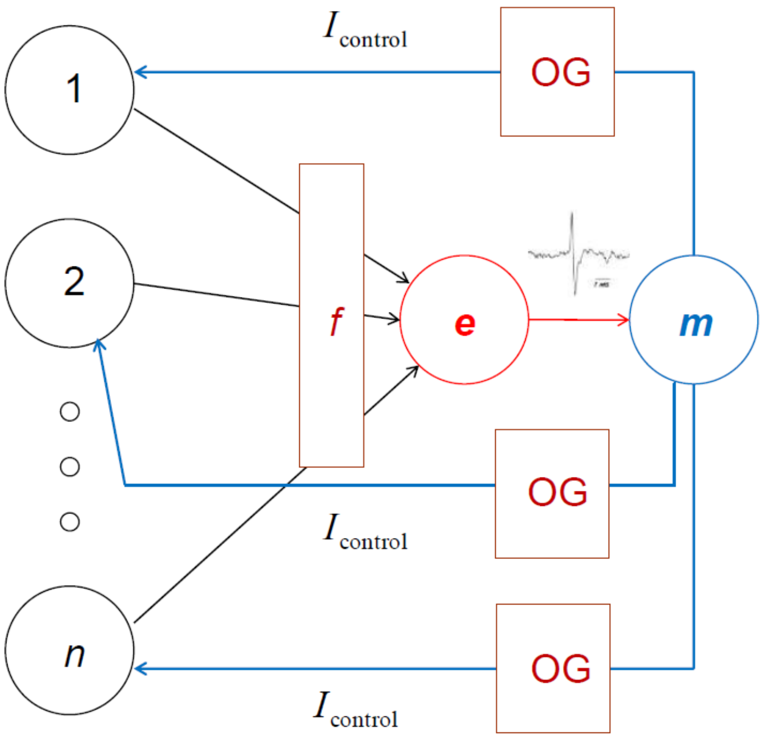

Figure 3. Optogenetic control scheme for detecting and suppressing the epileptiform dynamics.

The control scheme with the optogenetic feedback loop OG consist s of the following algorithmic steps:

- Form the function f over the action potentials of an arbitrary numbers of n neurons in the population.
- Make the Deutch-type measurement of the function f with the pair of control neurons e-m.
- If the function f is balanced, there is a normal regime in the population dynamics.
- If the function f is constant, there is an epileptiform regime in the population dynamics.
- If the epileptiform regime is detected, trigger the feedback suppressing control signal from the inhibitor control HH pair to the neurons of the population via the optogenetic feedback loop OG based on (11).

4. CONCLUSIONS

The algorithm proposed here can be efficiently used for driving the spiking and bursting regimes of neurons under optogenetic control.

This approach can be applied for the control over hyper-synchronized regime of the epileptiform behavior in ANNs.

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