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Natarajan Meghanathan
Dhinaharan Nagamalai (Eds)

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Natarajan Meghanathan,
Jackson State University, USA
E-mail: nmeghanathan@jsums.edu

Dhinaharan Nagamalai,
Wireilla Net Solutions, Australia
E-mail: dhinthia@yahoo.com

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Preface

The 7th International Conference on Computational Science and Engineering (CSE) April 27-28, 2019, Copenhagen, Denmark. 7th International Conference of Artificial Intelligence and Fuzzy Logic (AI & FL 2019), 6th International Conference on Computer Networks & Communications (CCNET 2019), 7th International Conference on Database and Data Mining (DBDM 2019), 6th International Conference on Signal Processing (CSIP 2019), 7th International Conference on Instrumentation and Control Systems (CICS 2019) was collocated with 7th International Conference on Computational Science and Engineering (CSE) The conferences attracted many local and international delegates, presenting a balanced mixture of intellect from the East and from the West.

The goal of this conference series is to bring together researchers and practitioners from academia and industry to focus on understanding computer science and information technology and to establish new collaborations in these areas. Authors are invited to contribute to the conference by submitting articles that illustrate research results, projects, survey work and industrial experiences describing significant advances in all areas of computer science and information technology.

The CSE 2019, AI & FL 2019, CCNET 2019, DBDM 2019, CSIP 2019, CICS 2019 Committees rigorously invited submissions for many months from researchers, scientists, engineers, students and practitioners related to the relevant themes and tracks of the workshop. This effort guaranteed submissions from an unparalleled number of internationally recognized top-level researchers. All the submissions underwent a strenuous peer review process which comprised expert reviewers. These reviewers were selected from a talented pool of Technical Committee members and external reviewers on the basis of their expertise. The papers were then reviewed based on their contributions, technical content, originality and clarity. The entire process, which includes the submission, review and acceptance processes, was done electronically. All these efforts undertaken by the Organizing and Technical Committees led to an exciting, rich and a high quality technical conference program, which featured high-impact presentations for all attendees to enjoy, appreciate and expand their expertise in the latest developments in computer network and communications research.

In closing, CSE 2019, AI & FL 2019, CCNET 2019, DBDM 2019, CSIP 2019, CICS 2019 brought together researchers, scientists, engineers, students and practitioners to exchange and share their experiences, new ideas and research results in all aspects of the main workshop themes and tracks, and to discuss the practical challenges encountered and the solutions adopted. The book is organized as a collection of papers from the CSE 2019, AI & FL 2019, CCNET 2019, DBDM 2019, CSIP 2019, CICS 2019

We would like to thank the General and Program Chairs, organization staff, the members of the Technical Program Committees and external reviewers for their excellent and tireless work. We sincerely wish that all attendees benefited scientifically from the conference and wish them every success in their research. It is the humble wish of the conference organizers that the professional dialogue among the researchers, scientists, engineers, students and educators continues beyond the event and that the friendships and collaborations forged will linger and prosper for many years to come.

Natarajan Meghanathan
Dhinaharan Nagamalai

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EVOLUTIONARY ALGORITHMS TO SIMULATE REAL CONDITIONS IN ARTIFICIAL INTELLIGENCE AS BASIS FOR MATHEMATICAL FUZZY CLUSTERING

Ness, S. C. C

Evocell Institute, Austria

ABSTRACT

In present-day physics we may assume space as a perfect continuum describable by discrete mathematics or a set of discrete elements described by a programmed probabilistic process or find alternative models that grasp real conditions better as they more closely simulate real behaviour. Clustering logic based on evolutionary algorithms is able to give meaning to unlimited amounts of data that enterprises generate and that contain valuable hidden knowledge. Evolutionary algorithms are useful to make sense of this hidden knowledge, as they are very close to nature and the mind. However, most known applications of evolutionary algorithms cluster data points to one group, thereby leaving key aspects to understand the data out and thus hardening simulations of biological processes. Fuzzy clustering methods divide data points into groups based on item similarity and detects patterns between items in a set, whereby data points can belong to more than one group. Evolutionary algorithm fuzzy clustering inspired multivariate mechanism allows for changes at each iteration of the algorithm and improves performance from one feature to another and from one cluster to another. It is applicable to real life objects that are neither circular nor elliptical and thereby allows for clusters of any predefined shape.

In this paper we explain the philosophical concept of evolutionary algorithms for production of fuzzy clustering methods that produce good quality of clustering in the fields of virtual reality, augmented reality and gaming applications and in industrial manufacturing, robotic assistants, product development, law and forensics as well as parameterless body model extraction from CCTV camera images.

KEYWORDS

Artificial Evolution, Artificial Intelligence, Biology, Big Data, Cellular Automata, Data Interpretation and Analytics, Deep Learning, Features Selection, Genetic Algorithms, Generative Models, Machine Learning, Pattern Recognition, Robotic Process Automation,Simulation, Smart Systems, Virtual Machines, Visualization.

1. FULL PAPER

In order to develop an ultimate model for the universe, the first step is to think about the nature of space. In present-day physics we may assume space as a perfect continuum describable by discrete mathematics or a set of discrete elements described by a programmed probabilistic process or find alternative models that grasp real conditions better as they more closely simulate real behaviour.

Philosophers have been known since ancient times to think deeply about the world around them. Everything they see, be it the stars in the night, the kebab in a Berlin snack bar or the naked

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breasts of a young sun worshipper, fills your mind with deep philosophical thoughts. One day a philosopher looks at the lawn in front of his kitchen. As he takes a closer look at a small part of the ground with its countless small blades of grass, he begins to doubt the concept of the lawn itself. Is what he sees really the lawn or does he see a single blade of grass and a single blade of grass and a single blade of grass? It's not about counting the individual blades of grass, the number has no meaning. It is important to see the plants with a single glance, each in its own particularity, its own character and its own difference. And not just to see them, to think them. The difficult thing, the philosopher states, is to grasp the whole as the sum of its parts. The philosopher is convinced that the lawn can only really be understood as a collection of blades of grass.

Our philosopher here is subject to a philosophical direction called reductionism, and this program is certainly seductive:

This reductionism is mostly motivated by the fact that people are impressed by the explanatory success of modern science.

Many theories since the Greek philosophers have shown that reduction is possible in many previously unexplained areas. It should therefore be assumed that reductions are also possible in previously unexplained areas. This is called the inductive argument for reductionism: if one does not understand something, one should break it down into its pieces, reduce it to its individual components. Since they are simpler than the whole, one has a greater chance of understanding these parts. And once you have understood them, you put everything back together again.
The question is: can we understand the concept of information through this particle-based reductionism? Does the investigation of a basic unit help us to uncover the true nature of information? Can we learn or simulate something by following the path postulated by Claude E. Shannon in the last century? Can we even divide the information itself into a measure that reflects its information content?

Although very widespread in computer science, arguments for this theory are not based on the history of science, but on considerations of causality. In classical argumentation there are causes for an event on different levels. For example, when a person takes a headache tablet. Then one can indicate different causes for this event.
Possible causes are, for example:

1. a mental explanation, such as the sensation of headache
2. biological processes that triggered certain muscle contractions
3.microphysical processes that cause other microphysical processes that realize tablet swallowing.

The fact that there can be several causes individually or together is a problem insofar as it is unclear whether these causes are independent of each other. After all, there is such a variety of causes in every action and it would be surprising if all these actions constantly have several independent causes. Proponents of reductionism like to argue that headaches are nothing more than a biological process and that every biological process is nothing more than a microphysical process or vice versa. If, however, one accepts multiple causes in solving the problem, one would also have to accept reductionism, since headaches are ultimately identified with a microphysical process.

This centuries-old conceptual reduction is very far removed from nature, i.e. just as far as it abstracts nature.

In the last century, Alan Turing (1912 to 1954) laid firm foundations, including the theoretical basis for universal calculating machines and the idea of artificial intelligence.

In 1936, he presented an abstract description of the solution to mathematical problems, which made him famous: "On Computable Numbers with an Application to the Decision Problem". The decision problem was a fundamental question of mathematics at the time. Put simply, it was about whether an algorithm could automatically find out that a mathematical statement is wrong or correct within a certain framework. Turing conceived - as a thought experiment - a machine with paper stiffeners as a storage medium, a kind of mechanized arithmetic artist: the so-called Turing machine. This computability model is one of the foundations of theoretical computer science today.

Most modern computers are the offspring of a computer built in 1948 based on Turing concepts in terms of their logic architecture.

Nevertheless, most artificial intelligences today are not based on advanced considerations, but on reductions that are based on statistical parameters, so that they can also be calculated with an ordinary calculator.

After all, Turing wanted to crack codes based on human logic in the Second World War. We want to simulate nature and thereby understand it.

How can and must growth and shape be so that today we can use them to simulate nature with a mathematical model? How can we describe morphogenesis, i.e. the development of organisms and organs, using mathematical models in individual areas of application?How does a small structure such as a blade of grass develop into a complex organism such as a lawn?

We see evolutionary algorithms in the field of artificial intelligence today as a class of stochastic, metaheuristic optimization techniques whose operational mode is inspired by the evolution of natural organisms. In those evolutionary algorithms we do not only use genetic programming, ie. the automatic creation or modification of computer programs using heuristic search algorithms to solve optimization and simulation by random selection, combination and variation of the desired parameters. Evolutionary programming of algorithms is different both in the sense that the structure of the program is constant so that only numerical values will change and in the sense that in the next generation only positive mutations are passed on.

As solutions for a certain problem are artificially evolved, those evolutionary algorithms are nature-analogous optimization methods. They show how learning and evolution interact, model ecosystems, immune systems, cognitive systems and social systems and thus useful to model artificial life using mathematics. Evolutionary algorithms do not usually find the best solution for a given problem if successful due to the assigned stochastic and metaheuristic algorithms. But if unsuccessful, they do find a sufficiently good solution, which is desirable in practice, especially for NP complete problems due to the number of mutations and because other NP complete problems are solved by mapping them onto the canonical problem. The methods of different evolutionary algorithms differ from each other primarily in selection, recombinations of the operators that were used, the problem representation and the kind of mapping applied. In evolutionary algorithms, complex functions evolve by building on simpler functions evolved previously, based on previous selection. In this scheme, the first genotypes able to perform a set number of tasks differ from their non-performing parents only by one or two or three mutations. But they differ from starting point of consideration ancestors by many mutations crucial to the new functionality. Complex useful functions can originate by random mutation and selection of a population and even deleterious mutations can serve as stepping-stones in the evolution of ground-breaking complex features.

The thinking model behind an evolutionary algorithm can be represented schematically as follows:

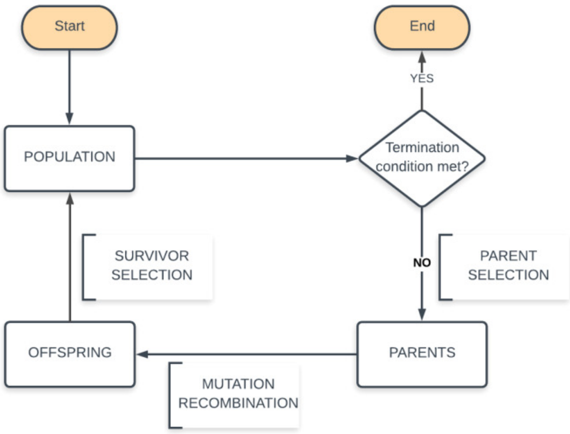

Figure 1: Schematic representation of evolutionary algorithms

The procedure of reproduction in evolutionary algorithm matches real world mutation amid generations of evolutions. The reproducibility of a solution to a given problem in evolutionary algorithms depends completely on what sort of arrangements you have and what sort of issue you wish to comprehend. In the mating capacity there is a variation operator which applies a mutation to the subsequent child solution and allows the next batch of solutions to "mutate" new features that may be superior to the features of the previous generation of solutions. In survivor selection upon incorporating the new functions there is a recognition among individual solutions dependent on their quality. The evolutionary algorithm selects the top performers of the solutions in this generation in a pre-set manner. Survivor selection iterates over many generations of evolution offspring and gives insights when the optimal fitness level is met by a candidate solution in the offspring pool.

Evolutionary algorithms are useful in order to map real life continuous natural selection processes: One aspect is that they are used in case of large or complex data, where regular algorithms need too much time and therefore stability is improved by an evolutionary approach. Another aspect is that biology as evolutionary algorithms help observe how a population looks like in generations. Artificial system inspired algorithms serve as models of living systems for the investigation of open questions in biology. Artificial life studies may help to understand open questions in understanding biological processes, including the origin of life, self-organization, cultural evolution, origin and maintenance of sex, balance in evolution, relations between fitness and adaptedness, structures of ecosystems and the nature of mind.

To sum it up, evolutionary algorithms help solve optimization and design problems by building solutions more fit relative to desired properties, thus leading to a computational evolution useful in the science of artificial intelligence by computers.

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A LEARNING CONTROLLER DESIGN APPROACH FOR A 3-DOF HELICOPTER SYSTEM WITH ONLINE OPTIMAL CONTROL

Guilherme B. Sousa[1*], Janes V. R.Lima[1], Patrícia H. M.Rêgo[2], Alain G.Souza[3] and João V. FonsecaNeto[4]

[1]Postgraduate Program in Computer Engineering and Systems, State University of Maranhão -UEMA, São Luís, MA, Brazil
[2]Mathematics and Computing Department, State University of Maranhão - UEMA, São Luís,MA, Brazil
[3]Technological Institute of Aeronautics, São José dos Campos, SP, Brazil
[4]Department of Electrical Engineering, Federal University of Maranhão - UFMA, São Luís, MA, Brazil

ABSTRACT

This paper presents the design and investigation of performance of a 3-DOF Quanser helicopter system using a learning optimal control approach that is grounded on approximate dynamic programming paradigms, specifically action-dependent heuristic dynamic programming (ADHDP). This approach results in an algorithm that is embedded in the actor-critic reinforcement learning architecture, that characterizes this design as a model-free structure. The developed methodology aims at implementing an optimal controller that acts in real-time in the plant control, using only the input and output signals and states measured along the system trajectories. The feedback control design technique is capable of an online tuning of the controller parameters according to the plant dynamics, which is subject to the model uncertainties and external disturbances. The experimental results demonstrate the desired performance of the proposed controller implemented on the 3-DOF Quanser helicopter.

KEYWORDS

Action-Dependent Heuristic Dynamic Programming, Actor-Critic Reinforcement Learning, Real-Time Control, 3-DOF Helicopter.

1. INTRODUCTION

The safe, reliable and efficient control of the complex systems (in which there are aircrafts, automobiles, electric energy systems, etc.) is essential for our society. Such automatic decision and control systems are omnipresent in the modern engineering techniques and have an enormous impact in our lives. The intrinsic complexity of such systems shows the need of improvements of decision and control methods which provide a guaranteed performance and the satisfaction of the prescribed objectives [1].

The optimazation of sequential decisions or controls that are repeated throughout the process comes in various fields, and the optimal control theory provides methods to compute feedback control systems that supply an optimal performance. The dynamic programming is a useful technique to deal with optimal control problems, although it is usually sensitive to computing, once the execution costs are very high, caused by the “curse of dimensionality” [2] to execute it

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and to obtain better solutions. The controllers optimize the performance functions prescribed by the user and normally are designed offline when solving the Hamilton-Jacobi-Bellman (HJB) equations. That requires knowledge of a complete model of the system dynamics. Nevertheless, in many situations it is difficult to determine the precise dynamic model for practical systems.
In nature, most organisms act in an optimal way to maintain resources while achieving their objectives. Such principle, characterized by strong self-learning and adaptation abilities, substantiates the approximate/adaptive dynamic programming (ADP), proposed by Werbos [3, 4], which has shown to be efficient to determine real-time optimal control policies in solving Hamilton-Jacobi Bellman (HJB) design equations online, forward in time, and it becomes an important method of intelligent control for non-linear systems [1, 5, 6].

In the approximate dynamic programming context, incremental methods are usually used to solve the online learning problem of critical network parameters to approximate a value function. Among the proposed iterative algorithms to estimate such parameters, we highlight the recursive least squares (RLS) learning. The efficiency of RLS methods in incremental actor-critical learning is mainly due to its robustness to deal with time variations in regression parameters and fast convergence speed compared to stochastic gradient methods [7].

RLS learning is emphasized under the perspective of the research and the development of ADP based control systems. Actor critic structures based on RLS were proposed in [8] to improve the efficiency of the conventional heuristic adaptive critic methods. In [9] and [10] the authors explore RLS methods to solve learning problems concerning the actor-critic reinforcement. Pietquin and others [11] presented a recent advance in temporal difference (TD) methods such as Kalman temporal difference (KTD). In this scheme, a Kalman filter is embodied in the estimative of the approximation process of the value function using a state space representation. A prior development on KTD paradigms is presented in the work by Geist and others [12] for deterministic markovi an decision processes.

For many traditional iterative ADP algorithms, it is necessary to build a non-linear system model and, then, execute the ADP algorithms to derive an improved control policy. In terms of RLS learning to solve the discrete-time algebraic Riccati equation (DARE), also known as HJB-Riccati equation, in optimal control problems that are solved by the Heuristic Dynamic Programming (HDP) approach, the authors [13] developed methods and algorithms based on the RLS training for the online design of the discrete-time linear-quadratic regulator (DLQR).

In contrast to the HDP approach, the Q learning, proposed by [14, 15], is an ADP algorithm based on data, which has been called action-dependent heuristic dynamic programming (ADHDP) [16]. For the Q learning algorithms, the function Q is used rather than the cost function of the traditional iterative ADP algorithms. The function Q, also termed as action value function, depends on both the state x and the control action u, which means that it includes the information about the system and the cost function, making the obtaining process of control policies from the function Q easier than through the traditional functions of performance index. [17]. For such characteristics, algorithms based on Q learning are preferable to obtain the optimal control for systems with unknown dynamics exclusively from the observed data throughout the system trajectories [17].

This work presents the conception of an RLS-based ADHDP algorithm for the online optimal control problem solution. Such iterative learning algorithm is based on policy iteration principle, where the policy improvements are performed at every time step along the realization of state trajectory towards the optimal policy. This control strategy is directed to the operation of a plant in the form of a helicopter with three degrees of freedom (3-DOF helicopter) which aims to represent in a simple way the dynamic of a real helicopter with two counter-rotating propellers that exempt the necessity of a tail rotor. In order to compensate for the effects of disturbances and variations in plant dynamics, the control system is designed so that the DLQR controller acts in real-time in plant control using only input and output signals measured along the system trajectory.

This work is organized as follows: Section 2 provides the system of equations of the 3-DOF Quanser helicopter system as well as its representation in state space, needed for the construction of the reference system to the proposed model. Section 3 provides, briefly, the fundamentals to assemble the optimal control design framework, which substantiates in the Bellman equation formulation in terms of the function Q, iteration principle of greedy policy and function approximation. It also presents the design method of the online optimal control system, that is based on the adaptive critic approach, where besides the gains of the DLQR controller are self-adjustable, the computing of the function Q is fully independent of plant model. The simulation results aiming at the optimal control and stabilization of the 3-DOF helicopter and that verify the performance of the RLS methods for the approximation of the action value function of the DLQR for the proposed algorithm in this work are presented in Section 4. Finally, the conclusions and commentaries are contained in Section 5.

2. System Description

The experimental platform used in this research is a three degree-of-freedom (3-DOF) helicopter, whose assembly is depicted in Figure 1, and in Figure 2 one can observe the schemes of the helicopter.

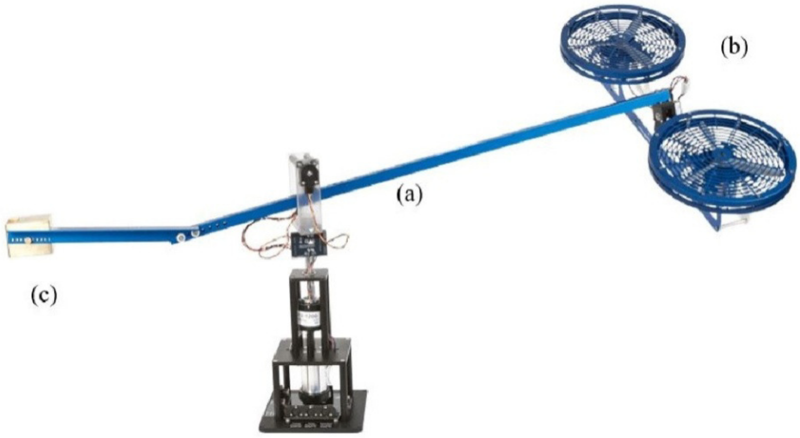

Figure 1. Configuration of the helicopter experimental system and its components: (a) main beam, (b) double rotor and (c) counterweight.

The 3-DOF helicopter is assembled over a stable basis and its primary components are the main beam, a set of a double rotor and the counterweight. The main beam is assembled in a way that allows the rotor assembly to rotate in continuous circles. This rotation movement is called travel. It occurs over a vertical axis which goes through a slip-ring and is perpendicular to the basis. In the bearing and slip-ring assembly there is a pivot point that allows the main beam to raise and lower. This movement is described as pitch or elevation, and it occurs about an axis which is parallel to the basis. In the longer end of the main beam, there is another bearing whose axis is parallel to the beam. It allows a set of double rotors driven by DC motors to rotate around that bearing. The rotational movement of the rotors is referred to as roll, and it occurs around an axis that goes through the main beam. The motors may provide collective or differential (cyclic) voltage. The collective voltage generates the elevation movement of the main beam, and the differential voltage generates the roll movement. The roll movement of the rotors, in turn, originates the travel movement of the assembly. In the other end of the main beam, there is a counterweight that reduces the energy requirements in the motors, reducing the effective weight of the rotor assembly.

The dynamic of the helicopter can be described by a sixth-order nonlinear model, and for the derivation of the equations of the system, a system of coordinates with its origin in the set of bearing and slip-ring is used, being the travel (ψ) the circular movement of the main beam, roll (ϕ) the movement of the set of rotors, and elevation (θ) the up and down movement of the beam, as well as its respective velocities (travel velocity ($\dot{\psi}$), roll velocity ($\dot{\phi}$), and elevation velocity ($\dot{\theta}$)). The corresponding angles are shown in Figure 2.

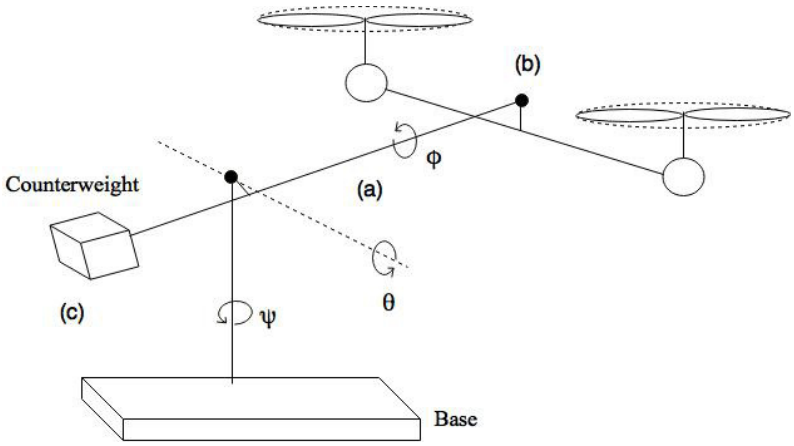

Figure 2. Configuration of the helicopter experimental system.

In this way, the state equation can be expressed as

$$\dot{x} = f(x, u) \quad (1)$$

in which $x = \begin{bmatrix}\phi & \dot{\phi} & \theta & \dot{\theta} & \psi & \dot{\psi}\end{bmatrix}^T$ and $u = [u_1 u_2]^T$, where the control variables $u_1$and $u_2$corresponding to the voltages given to the left and right motors, respectively.

To simplify the hypothesis, it is considered that the inertia of the helicopter can be represented bypoint masses associated with the body of the helicopter, the counterweight, the gravity center of the sustentation bundle, and with the mass position of active disturbance. Besidesthat, there are the viscous friction effects in the equations that describe the dynamic of the pitchand travel movements, aiming to make it more realistic for the simulation,disregarding the airresistance and the angular moment of the propellers that rotate in the same direction. The forcesgenerated by the propellers do not depend on the relative movement of the body of the helicopter regarding the air. Ultimately, the electromechanical dynamic of the motor-propollers sets is disregarded,which is much faster than the movement dynamic of the system as a whole.

The 3-DOF helicopter has been an object of study of several works in the literature, such as [18 – 21]. Among the proposed models to represent the dynamic of the helicopter, the one presented in[19] was used here. Such model was obtained through the formalism of Lagrange, being nonlinearand sixth-order. Through some mathematical simplifications, this model can be expressed by thefollowing set of differential equations:

$$\dot{x}_1 = x_2$$
$$\dot{x}_2 = \xi_{16} \cdot \{\xi_1(u_1^2 - u_2^2) + \xi_2(u_1 - u_2) - v_2 \cdot x_2\}$$

$$\dot{x}_3 = x_4$$
$$\dot{x}_4 = x_6^2 \cdot \{\xi_3 \cdot \sin(2x_3) + \xi_4 \cdot \cos(2x_3)\} + \xi_5 \cdot \sin(x_3) + \xi_6 \cdot \cos(x_3) + \{\xi_7(u_1^2 + u_2^2) + \xi_8(u_1 + u_2)\} \cos(x_1)$$
$$\dot{x}_5 = x_6 \quad (2)$$
$$\dot{x}_6 = \{\xi_{13} + \xi_{14} \cdot \sin(2x_3) + \xi_{15} \cdot \cos(2x_3)\}^{-1} \cdot \{v_1 - v_3 \cdot x_6 + [\xi_9(u_1^2 + u_2^2) + \xi_{10}(u_1 + u_2)] \cdot \sin(x_1) + x_4 \cdot x_6 \cdot [\xi_{11} \cdot \sin(2x_3) + \xi_{12} \cdot \cos(2x_3)]\}$$

in which x_1,$x_3$and $x_5$represent the roll, elevation and travel angles (in rad), x_2,$x_4$and $x_6$represent their respective derivatives (rad/s), and $u_1$and $u_2$represent the input voltages of the left andright motors. The other parameters are constants related to the physical dimensions and masses ofthe various components of the helicopter, as well as the constants related to the viscous friction,and their used values are presented in Appendix A.

3. ADHDP FOR ONLINE OPTIMAL CONTROL

The Action-Dependent Heuristic Dynamic Programming (ADHDP) framework for online designof discrete linear quadratic regulator (DLQR) control systems is presented in this section. It isdescribed how to implement an optimal adaptive control using reinforcement learning guided bygreedy iteration schemes and function approximation methods to obtain optimal decision policies online in real-time. Qlearning is a reinforcement learning method that results in an adaptivecontrol algorithm for optimal control solution for completely unknown systems. The parametrizations of Bellman's equation, the utility function and the dynamic system assemble the frameworkof online optimal control design, where the DLQR control policy is estimated online in real-timedirectly from data observed along the system trajectories, this means that the controller proposedsolve the Riccati equation without knowing the system matrix.

3.1. Bellman-DLQR Problem Formulation

The models of the dynamic system f and of the control policy h are linear mappings that arerepresented for combiners of the states and inputs. The state $f(x_k, u_k)$ and decision policy $h(x_k)$parameterizations [22] are given by

$$f(x_k, u_k) = Ax_k + Bu_k \quad (3)$$

and

$$u_k = h(u_k) = -Ku_k \quad (4)$$

where $A \in \Re^{n \times n}$, n is the order of the system, $x \in \Re^n$ is the state, $B \in \Re^{n \times n_e}$, n_e is the amount of control inputs, $u \in \Re^{n \times n_e}$ is the control input, and $K(\cdot) \in \Re^{n_e \times n}$ is the matrix of state feedback gains.

The utility function r associated with the system (3)-(4) has a quadratic form that is given by

$$r(x_k, u_k) = x_k^T Q x_k + u_k^T R u_k \quad (5)$$

with weighting matrices $Q = Q^T \geq 0$ and $R = R^T > 0$ symmetric [23].

For the DLQR control design, the parametrizations of the utility function, Eq.(5), and decision(control) policy, Eq.(4), are replaced in the state-value function $V^h(x_k) = \sum_{i=k}^{\infty} \gamma^{i-k} r(x_i, h(u_i))$to obtain the parameterized DLQR cost function.

$$V^h(x) = r\big(x, h(x)\big) + \gamma V^h f\big(x, h(x)\big) \tag{6}$$

where $0 < \gamma \leq 1$ is the discount factor. So, the goal is to establish an control or decision policyh^*that minimizes the discounted sum of the instantaneous costs, which satisfies the inequality$V^{h^*}(x) \leq V^h(x)$. According to Bellmman's optimality principle, the optimal cost V^*satisfiesthe discrete time HJB equation [24], as follows

$$V^*(x) = \min_{h(\cdot)}\{r\big(x, h(x)\big) + \gamma V^* f\big(x, h(x)\big)\} \tag{7}$$

3.2. DLQR based on$Q$ Learning

The action-dependent heuristic dynamic programming (ADHDP) approach is based on the Qlearning, which consists of a model free method that estimates the function Q for any optimalor non-optimal policy [25, 26] based only the state transition cost samples of the instantaneouscost function. The function Q, or the action-value function, is defined as [27]

$$Q^h(x_k, u_k) = r(x_k, u_k) + \gamma V^h f(x_k, u_k) \tag{8}$$

From the equation (8), it can be seen that given a fixed policy$V^h(x) = Q^h\big(x, h(x)\big)$.Thus, thefunction Q and the optimal function Q^*can be expressed in the Bellman form by

$$Q^h(x_k, u_k) = r(x_k, u_k) + \gamma Q^h(x_{k+1}, h(x_{k+1})) \tag{9}$$

$$Q^*(x_k, u_k) = r(x_k, u_k) + \gamma Q^*(x_{k+1}, h(x_{k+1})) \tag{10}$$

where the optimal control policy is given by

$$h^*(x_k) = \arg\min_{u_k} Q^*(x_k, u_k) \tag{11}$$

In [28] and [23], it is possible to see that for the DLQR, the function Q is quadratic in terms of z, that is,

$$Q(x_k, u_k) = z_k^T S z_k \tag{12}$$

where $z_k^T = [x_k^T \quad u_k^T]$, and S is the learning matrix associated with the function Q, which is given by

$$S = \begin{bmatrix} S_{xx} & S_{xu} \\ S_{ux} & S_{uu} \end{bmatrix} \tag{13}$$

where $S \in \Re^{(n+n_e)\times(n+n_e)}$and the matrices S_{xx}, S_{xu}, S_{ux} e S_{uu} represent the weightings of the state x and the control policy u.

The minimization of the parametrized function Q provides the means to determine the optimalpolicy u^*. The gradient equation$\partial Q/\partial u = 0$, when solved for u, gives the optimal policy u^*,which is described by

$$u^* = K(S)x \tag{14}$$

where $K(S) = -S_{uu}^{-1}S_{ux}$

The parametrization $Q(S)$ induces a policy parametrization $h(S)$. According to the parametrization$u = h(x, \kappa)$ of the control policy, the parameters vector κ is a vectorization of the gain matrix$K$, i.e. $\kappa = vec(K)$ [23].

3.3. RLS-ADHDPApproximation

The method for online optimal control design that will be described in this section is based on theadaptive critic approach and ADHDP algorithms [28, 29]. Such algorithms are developed in thecontext of online DLQR control design that provide the solution of the Riccati equation and theRiccati optimal gain K using greedy iteration schemes.

Considering the quadratic form (12) and (13), assume that, for nonlinear systems, the function Q is parameterized as

$$Q(x,u) = \varphi^T(z)\theta \tag{15}$$

for some unknown weight vector $\boldsymbol{\theta} = \left[\theta_1\theta_2 \ \ldots \ \theta_{n_\theta}\right]^T$, where $n_\theta = (n + n_e)(n + n_e + 1)/2$ corresponds to the number of parameters to be estimated, and a basis functions vector $\boldsymbol{\varphi}(z) = \left[\phi_1(z)\ \phi_2(z) \ \ldots \ \phi_{n_\theta}(z)\right]^T$, with $z_k = [x_k^T \quad u_k^T]^T$.For the parameter vector $\boldsymbol{\theta}$ estimation problem, the recursive least squares (RLS) method is considered. Such approach aims at carrying out online learning for optimal control via cost function estimatives of a given policy, constructed from the data $(z_k, z_{k+1}, r(x_k, u_k))$, which are observed throughout the system trajectory.

The criteria used in the policy evaluation based on optimization make the Q learning structure a critic adaptive scheme where the policy iteration step (critic network) determines the least squares solution to $\boldsymbol{\theta}_{k+1}$

$$(\boldsymbol{\varphi}^T(z_k) - \gamma\boldsymbol{\varphi}^T(z_{k+1}))\boldsymbol{\theta_k} = x_k^T Q x_k + u_k^T R u_k \tag{16}$$

and the policy improvement step (action network) determines an improved policy that is given by

$$h_{k+1}(x_k) = \arg\min_{h(\cdot)}(\phi^T(z_k)\boldsymbol{\theta}_k) \tag{17}$$

where each pair of weightings Q and R defines a different controller. Therefore, exploring the possible weighing space, one approximates the dynamic programming solution for the optimal controller. ADHDP is a method which improves the controller from an iteration to the next, from the time instant k until the instant $k + 1$ [29].

The matrix vectorization and the Kronecker product theory [13, 30] contribute for an approximate solution of the HJB-Riccati equation obtained through an iterative scheme such as

$$\phi^T(z_k)\boldsymbol{\theta}_k = r(x_k, u_k) \tag{18}$$

where $\boldsymbol{\theta}$ is the parameter vector corresponding to the matrix S vectorization, $\phi^T(z_k)$ is the regression vector and $r(x_k, u_k)$ is the target, which are given by

$$\phi_k = z_k^T \otimes z_k^T$$

$$=[z_{1,k}^2; z_{1,k}z_{2,k}; z_{2,k}^2; \ldots; \ z_{n-1,k}z_{n,k}; z_{n,k}^2]^T - \tag{19}$$

$\gamma[z_{1,k+1}^2; z_{1,k+1}z_{2,k+1}; z_{2,k+1}^2; \dots; z_{n-1,k+1}z_{n,k+1}; z_{n,k+1}^2]^T$

$$r(x_k, u_k) = x_k^T Q x_k + u_k^T R u_k \tag{20}$$

The problem consists in determining a parameter vector $\boldsymbol{\theta}$ estimative from a set of pairs of observations and regressors $\{(d(\cdot), \phi_k, k = 1, 2, \dots, N\}$, taking in accountonline designs for real-time applications. The least squares estimative of $\boldsymbol{\theta}$ is defined as the vector that minimizes the following cost function

$$J(\theta, N) = \sum_{k=1}^{N} \mu^{N-k} [r(x_k, u_k) - \phi_k^T \boldsymbol{\theta}]^2 \tag{21}$$

where μ is the forgetting factor, $0 < \mu \leq 1$, and N is the number ofsample data.
The least-squares solution of the problem (21) is given by [31]

$$\boldsymbol{\theta}_N = \boldsymbol{\Phi}_N^{-1} \boldsymbol{\eta}_N \tag{22}$$

where$\boldsymbol{\Phi}_N = \sum_{k=1}^{N} \mu^{N-k} \phi_k \phi_k^T$is the correlation matrix, $n_\theta \times n_\theta$, of the input data vector ϕ, and $\boldsymbol{\eta}_N = \sum_{k=1}^{N} \mu^{N-k} \phi_k r(x_k, u_k)$ is the crossed correlation vector between the LS estimator inputs and the desired response.

Through algebraic manipulations, Eq.(22) is developed in a recursive form given by

$$\boldsymbol{\theta}_k = \boldsymbol{\theta}_{k-1} + \boldsymbol{\Phi}_k^{-1} \phi_k \left(r(x_k, u_k) - \phi_k^T \boldsymbol{\theta}_{k-1} \right) \tag{23}$$

where $\boldsymbol{\Phi}_k$ is a recursive form given by

$$\boldsymbol{\Phi}_k = \mu \boldsymbol{\Phi}_{k-1} + \phi_k \phi_k^T \tag{24}$$

Applying the matrix inversion lemma to the Eq.(24), the RLS estimation in the forms (23)-(24) can be rewritten as

$$\boldsymbol{\theta}_k = \boldsymbol{\theta}_{k-1} + \boldsymbol{L}_k \left(r(x_k, u_k) - \phi_k^T \boldsymbol{\theta}_{k-1} \right) \tag{25}$$

where

$$\boldsymbol{L}_k = \boldsymbol{\Gamma}_k \phi_{\boldsymbol{k}} = \frac{\boldsymbol{\Gamma}_{k-1} \phi_{\boldsymbol{k}}}{\mu + \phi_k^T \boldsymbol{\Gamma}_{k-1} \phi_{\boldsymbol{k}}} \tag{26}$$

and

$$\boldsymbol{\Gamma}_k = \mu^{-\mathbf{1}} (\boldsymbol{\Gamma}_{k-1} - \boldsymbol{L}_k \phi_k^T \boldsymbol{\Gamma}_{k-1}) \tag{27}$$

where the matrix Φ, $n_\theta \times n_\theta$, is the inverse of correlation matrix/covariance matrix, and $L_k$is thegain vector, $n_\theta \times 1$.

The ADHDP algorithm main core is developed according to the Eqs.(18)-(22) for theonline implementation based on RLS. The observed data throughout the system trajectoryis$(z_k, z_{k+1}, r(x_k, u_k))$ with $z_k = [x_k^T \quad u_k^T]^T$. The vector$z_{k+1} = [x_{k+1}^T \quad u_{k+1}^T]^T$is computed using$u_{k+1} = h_k(x_{k+1})$ where$h_k(\cdot)$ is the current policy. A probing noise mustbe added to the control input as a conditionto obtain the persistence of excitation, whichis$u_k = -Kx_k + \epsilon_k$[22]. That scheme is capable ofsolving the HJB-Riccati equation online with noknowledge of the system dynamics.

3.3.1. RLS$_\mu$ – ADHDP-DLQR Algorithm

TheRLS$_\mu$-ADHDP-DLQR algorithm has two main blocks that are responsible for the policyevaluation and policy improvement steps to determine the control policy based on reinforcement learning methods. In the block of policy evaluation, Kronecker product (steps 25-27) and theequations of the RLS estimator (step 28) are executed so the matrix S is approximated, followedby the policy improvement (steps 31-32) block, the latter is a greedy policy with respect to theapproximation $S^{\theta_{k+1}}$. The block 0 contains the fixed parameters of the system inherent to theoptimization problem, which are the weighing matrices Q and R, the matrices A and B of thedynamic system, and the discount fator γ. The forgetting factor μ, the parameter θ, and thematrix$\boldsymbol{\Gamma}$ are the necessary conditions for the RLS estimation problem.

ALGORITHM 1 - RLS$_\mu$-ADHDP-DLQR

---

1 ► **Block 0 – Initialization**
2 ► Weighting and Dynamic System Matrices – Q, R, A_d, B_d
3 ► Initial Policy – K_0
4 ► State Resetting – x_{revit}, n_{revit}
5 ► Initial State – x_0
6 ► Discount Factor – $0 < \gamma \leq 1$
7 ► RLS$_\mu$Parameters:θ_0,Γ_0
8 ► Forgetting Factor – $0 < \mu \leq 1$
9 ► Iteration Number – N.

---

10 ► - Iterative Process
11 ► **for**$k \leftarrow 0 : N$
12 **do**
13 ► **Block 1– Environment Simulation**
14 Control Noise (Probing noise of control signal)
15 $\epsilon_k \leftarrow [\ \ ]$
16 Control Action
17 $u_k \leftarrow -K_k x_k + \epsilon_k$
18 States
19 $x_{k+1} \leftarrow A_d x_k + B_d u_k$
20 Next Control Action
21 $u_{k+1} \leftarrow -K_k x_{k+1}$

---

22 ► **Block 2– Approximate Policy Evaluation**
23 ► Target Assembling
24 $r(x_k, u_k) \leftarrow x_k^T Q x_k + u_k^T R u_k$
25 ► Basis Set - Kronecker Product
26 $\phi_k = [z_{1,k}^2; z_{1,k}z_{2,k}; z_{2,k}^2; \dots; z_{n-1,k}z_{n,k}; z_{n,k}^2]^T - \gamma[z_{1,k+1}^2;$
27 $\dots; z_{1,k+1}z_{2,k+1}; z_{2,k+1}^2; \dots; z_{n-1,k+1}z_{n,k+1}; z_{n,k+1}^2]^T$
28 ► Recursive least-square : Update$\boldsymbol{\theta}_{k+1}$ via RLS recurrence (25)-(27)
29 ► Smatrix recovery from vectorθ
30

$$S^{\theta\ k+1} \leftarrow \begin{bmatrix} \theta_1 & \theta_2/2 & \cdots & \theta_{(n+n_e)}/2 \\ \theta_2/2 & \theta_{(n+n_e)+1} & \cdots & \theta_{2(n+n_e)-1}/2 \\ \vdots & \vdots & \ddots & \vdots \\ \theta_{(n+n_e)}/2 & \theta_{2(n+n_e)-1}/2 & \cdots & \theta_{n_\theta} \end{bmatrix}$$

---

31 ► **Block 3– Policy Improvement** (Feedback Optimal Gain K)
32 $K_{k+1} \leftarrow (S_{uu}^{\theta_{k+1}})^{-1}(S_{ux}^{\theta_{k+1}})$

---

33 **if**$i\%n_{revit} = 0$
34 **then**

$x_{k+1} \leftarrow x_{revit}$

End – Iterative Process

4. SIMULATIONRESULTS

In this section, the simulation results of the online optimal control design for the 3-DOF Helicopter system are presented, using an adaptive critic scheme based on greedy policy iterationtechnique.The typical parameters of configuration of the 3-DOF helicopter system are presented in AppendixA. The controller design via ADHDP is established aiming at maintaining the stabilization of the3-DOF helicopter system in real-time, taking into account the iterative process configuration , aswell as the reference policy, which is established offline by Schur's solution [32] for the HJB-Riccati equation.

The linearization for the adopted operation point of the nonlinear model of the helicopter wascarried out using the parameters given in Appendix A. The matrices of the linear continuousmodel are expressed as:

$$A = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & -0.753 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ -0.098 & 0 & -1.192 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ -1.257 & 0 & 0 & 0 & 0 & -0.457 \end{bmatrix} \quad (28)$$

And

$$B = \begin{bmatrix} 0 & 0 \\ 2.814 & -2.814 \\ 0 & 0 \\ 0.394 & 0.394 \\ 0 & 0 \\ -0.035 & -0.035 \end{bmatrix} \quad (29)$$

The chosen output variables were the roll, elevation and travel angles ($y = [\phi \theta \ \psi]^{\mathrm{T}}$). Besidesthat, since there is no direct transmission between inputs and outputs of the plant, the C and Dmatrices were defined as

$$C = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \end{bmatrix} \text{and } D = [0] \quad (30)$$

For many executed simulations, the influence of the forgetting factor μ can be verified in theconvergence process for the solution of the HJB-Riccati equation with different values of μ. Inthis approach, the algorithm presents a revitalization condition due to null-state problems that leadthe matrix of regressors to a null rank [7]. So, it is necessary to perform the system revitalizationafter each interval $n_{\ revit}$, which is given by the dimension of the regression vector ϕ_k.

For the implementation of the RLS$_{\mu}$-ADHDP-DLQR algorithm the initial conditions and systemparameters are: an admissible initial policy K_0; discount fator γ; initial state of the system$x_0 = [0.18 \ -0.19 \ -0.32 \ 0.61 \ -0.5]^T$ for the angles in radians and quadratic matrices of the cost function respectively given by $Q = [0.1\,0\,0\,0\,0\,0;\ 0\,1\,0\,0\,0\,0;\ 0\,0\,1\,0\,0\,0;\ 0\,0\,0\,0.01\,0\,0;\ \ldots;\ 0\,0\,0\,0\,1\,0;\ 0\,0\,0\,0\,0\,1];R =$

$[10^2\ \ 0; 0\ \ 10^2]$. The parameters that initialize the proposed RLSestimator are given by vector $\boldsymbol{\theta}_0 = 10^3 * [1\,0\,0\,0\,0\,0\,0\,0\,1\,0\,0\,0\,0\,0\,0\,1\,0\,0\,0\,0\,0\,1\,0\,0\,0\,0\,1\,0\,0\,0 \ldots 1\,0\,0\,1\,0\,1]^T$; and matrix $\Gamma_0 = 10 * I_{36\times36}$, where I is na identity matrix of order n_θ. The matrices of the discretized system for the sampling interval $T = 0.1$ are obtainedthrough the zero-orderhold (ZOH) method. For the simulations the following values of μ are considered: 0.7640 and0.9802.

4.1. Forgetting Factor $\mu = 0.764$

The evolution of the iterative process of the Q-function estimation by the $\mathrm{RLS}_\mu - \mathrm{ADHDP} - \mathrm{DLQR}$algorithm is presented in Figure 3 for a cycle of 5000 iterations, considering the forgetting factor $\mu = 0.764$. The curves (a)-(f) of Figure 3 represent the convergence behavior of the elements s_{11}, s_{26}, s_{33}, s_{55}, s_{74} and s_{87} of the matrix S corresponding to the componentes θ_1, θ_{13}, θ_{16}, θ_{27}, θ_{25}andθ_{35} of the parameter vector θ, respectively. There was a quick convergence, without large oscillations during the transitory period, which was achieved after only 1600 iterations.

The control strategy was adopted to solve the regulation problem of the helicopter, that is to maintain the 3-DOF helicopter in a steady and pre-stablished flight condition, considering restrictionsof the helicopter angles (which can be interpreted as obstacles that limit its maneuvering space),restrictions of control variables and external disturbance.

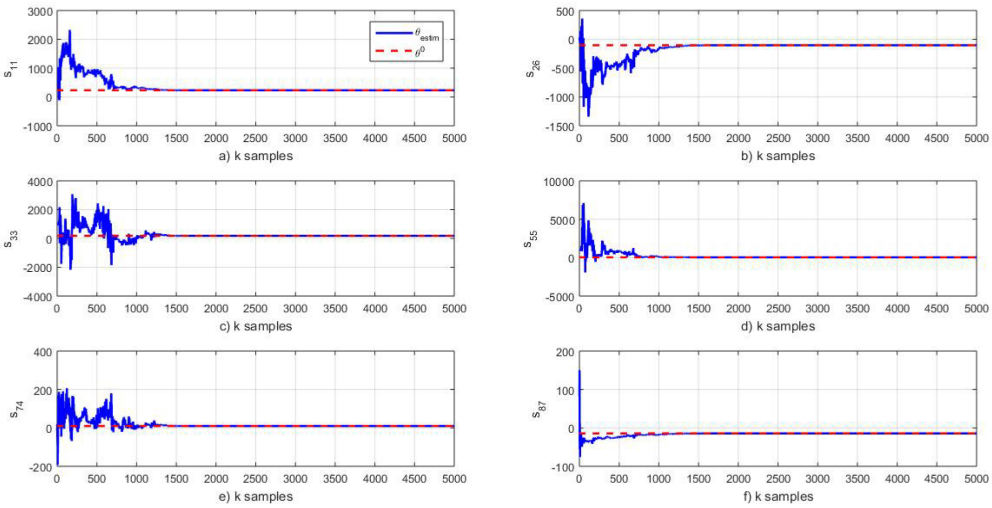

Figure 3.Evolution of the iterative process for the parameterss_{11}, s_{26}, s_{33}, s_{55}, s_{74} and s_{87} for 5000 cycle of iterations, with the forgetting fator $\mu = 0.764 - \mathrm{RLS}_\mu - \mathrm{ADHDP} - \mathrm{DLQR}$

Figures 4 and 5 correspond to the control effort and the state trajectories of the system,respectively,from the action-environment-observation interactivity of the dynamic system simulator for the$\mathrm{RLS}_\mu - \mathrm{ADHDP} - \mathrm{DLQR}$ algorithm.

From Figure 5, one can observe that the values of the states concentrate in a range that correspondsto the equilibrium point of the system. The recurring variations of the control effort in Figure 4indicate the effort at regulating, the states in a quick way, so that the plant of the 3-DOF Helicopter is in conformity with the pre-established design.

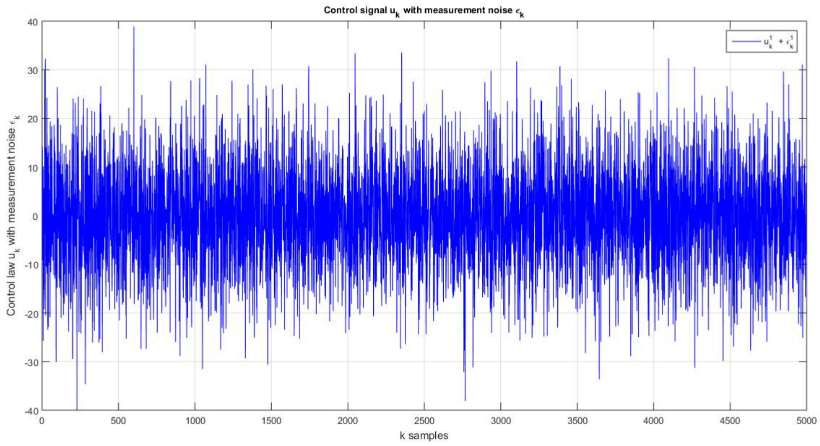

Figure 4.Control signal with tracking noise

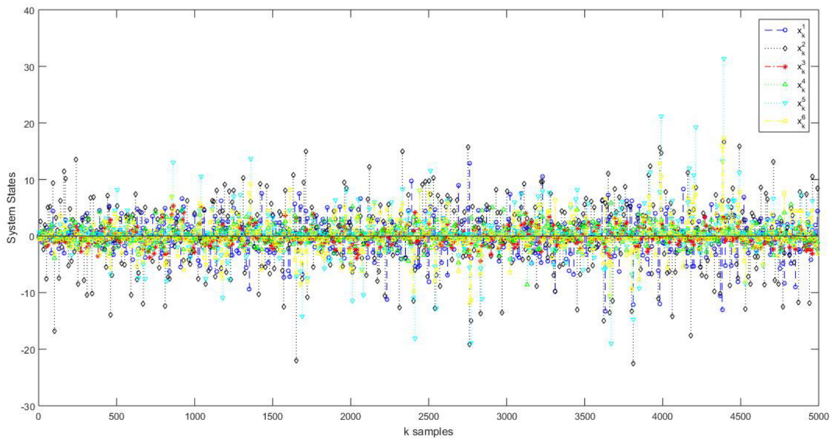

Figure 5.States x_1, x_2, x_3, x_4, $x_5$andx_6 of the system for some samples

4.2. Forgetting Factor $\mu = 0.9802$

For a cycle of 5000 iterations, the evolution of the iterative process of the Q-function estimation by the $\mathrm{RLS}_\mu - \mathrm{ADHDP} - \mathrm{DLQR}$algorithm is presented in Figure 6, considering the forgetting factor $\mu = 0.980$. The curves (a)-(f) of Figure 6 represent the convergence behavior of the elements s_{11}, s_{26}, s_{33}, s_{55}, s_{74} and s_{87} of the matrix S correspondents to the componentes θ_1, θ_{13}, θ_{16}, θ_{27}, θ_{25}andθ_{35} of the parameter vector θ, respectively. There was a subtle convergence, without large oscillations during the transitory period, which was achieved after only 1600 iterations.The same smooth convergence that took place for thefactor $\mu = 0.764$also happened to the factor $\mu = 0.9802$, thedifference between the two factors is the accommodation time. One can observe throughout thesimulations that for higher factors the convergence time tends to grow. For the forgetting fator $\mu = 0.9802$, the convergence was achieved after only 2500 iterations.

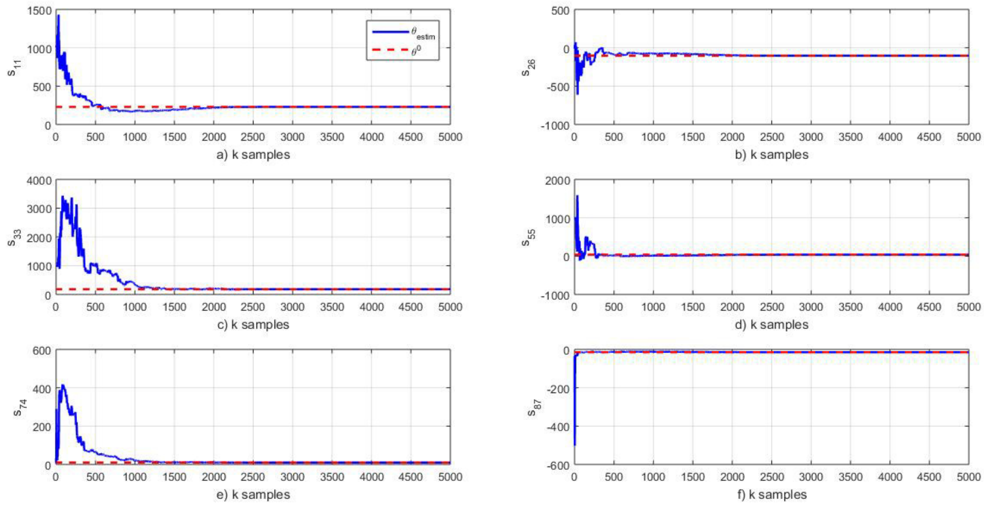

Figure 6.Evolution of the iterative process for the parametersss_{11}, s_{26}, s_{33}, s_{55}, s_{74} and s_{87} for 5000 cycle of iterations, with the forgetting fator $\mu = 0.764 - \mathrm{RLS}_{\mu} - \mathrm{ADHDP} - \mathrm{DLQR}$

As for the previous factor, we have in Figures 7 and 8, respectively, the control effort added to thetracking noise and the trajectories of the system states. The chosen operating point remains thesame, corresponding to the situation in which the helicopter finds itself still with elevation angle 14degrees below horizontal position. Suppose that the changes in the forgetting factor (disturbances)affect the input variables of the system, as one can see in Figure 8.

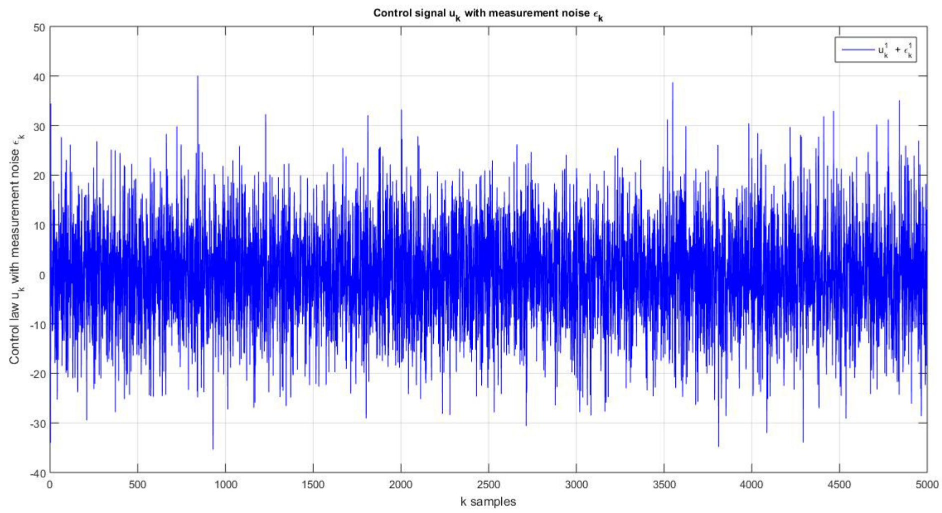

Figure 7.Control signal with tracking noise

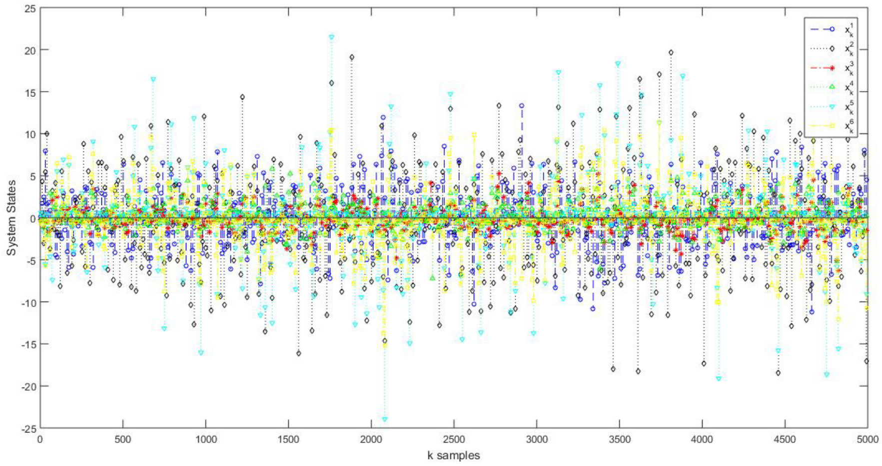

Figure 8.States x_1, x_2, x_3, x_4, $x_5$andx_6 of the system for some samples

The ADHDP methodology via process of RLS estimation of the optimal DLQR decision policies represent a method that performs the RLS approximation of the solution of the HJB-Riccati equation in the context of adaptive optimal control project in real-time based on the structure of learning by effort over a greedy policy iteration. Such methodology seems pretty successfulregarding the control and stabilization of the system of the 3-DOF helicopter, being that form a reference for the study and control of systems whose mathematical model is complex for the controlprocess in real-time.

5. SIMULATIONRESULTS

In the present design, the adaptive critic method, based on greedy policy iterations, wasemployedfor obtaining solutions of online optimal control problems of discrete-time nonlinear systems,especially the control and stabilization problem of a 3-DOF helicopter.

First of all, a mathematical model was adopted for the 3-DOF helicopter system for getting aprocess simulator for the ADHDP-DLQR design purpose. In the performance evaluation of the$\mathrm{RLS}_{\mu} - \mathrm{ADHDP} - \mathrm{DLQR}$algorithm, one can verify with respect to the selection of the forgettingfactor, its large influence in the convergence process for the solution of the HJB-Riccati equation.The aim of the proposed methodology is to improve the ADHDP approach performance via RLS estimation of the DLQR optimal decision policies.

The results were promising for the multivariable dynamic system models, since the appropriatechoice of the forgetting factor considerably improves the performance of the $\mathrm{RLS}_{\mu} - \mathrm{ADHDP} - \mathrm{DLQR}$ method. The use of UDU^Tfactorization, as well as of the $Q\mathcal{R}$ decomposition used inthe critic net of the algorithm are one of our main research topics in the future, aiming to overcome problems inherent to the RLS estimation such as the numeric stability loss of the covariancematrix, causing a possible convergence loss of the systems under study.

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A. APPENDIX

Table 1. Parameter values

Parameter	Value	Parameter	Value
ξ_1	0,1117 N/V^2	ξ_{11}	1,0567 kg·m^2
ξ_2	0,0449 N/V	ξ_{12}	-0,2515 kg·m^2
ξ_3	-0,4843	ξ_{13}	0,5454 kg·m^2
ξ_4	0,1153	ξ_{14}	0,1258 kg·m^2
ξ_5	-1,0389 N/(m·kg)	ξ_{15}	0,5283 kg·m^2
ξ_6	-1,3170 N/(m·kg)	ξ_{16}	4,1832 (m·kg)$^{-1}$
ξ_7	0,0656 N/(m·kg·V^2)	v_1	0,107 N·m
ξ_8	0,0264 N/(m·kg·V)	v_2	0,18 N·s
ξ_9	-0,0718 N·m/V^2	v_3	0,47 N·m·s
ξ_{10}	-0,0289 N·m/V	-	-

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METHOD FOR THE DETECTION OF CARRIER-IN-CARRIER SIGNALS BASED ON FOURTH-ORDER CUMULANTS

Vasyl Semenov[1], Pavel Omelchenko[1] and Oleh Kruhlyk[1]

[1]Department of Algorithms, Delta SPE LLC, Kiev, Ukraine

ABSTRACT

The method for the detection of Carrier-in-Carrier signals based on the calculation of fourth-order cumulants is proposed. In accordance with the methodology based on the "Area under the curve" (AUC) parameter, a threshold value for the decision rule is established. It was found that the proposed method provides the correct detection of the sum of QPSK signals for a wide range of signal-to-noise ratios. The obtained AUC value indicates the high efficiency of the proposed detection method. The advantage of the proposed detection method over the "radiuses" method is also shown.

KEYWORDS

Carrier-in-Carrier, Cumulants, QPSK.

1. INTRODUCTION

The development of digital communications creates the need to develop more efficient methods for using frequency resources. Although modern methods of error-correction coding allow working at rates close to the theoretical Shannon limit, channel capacity can be increased by using Carrier-in-Carrier (also known as PCMA, Paired-Carrier Multiple Access) technologies in which the transmitted signals occupy the same band (see, for example, [1]).

There are various methods of blind separation for the sum of several signals (see [2-3]), including PCI (Principal informative components), ICA (Independent Components Analysis)], Particle Filtering and other approaches. In [4], a method of blind separation was also proposed, based on the iterative maximization of a posteriori probability density of the separated signals.

At the same time, the task of *detecting* the fact of transmitting a superposition of signals at a given frequency is practically not considered in the literature. This task has importance for the tasks of non-cooperative communication and electronic reconnaissance. Therefore, in this paper we propose a method for detecting such signals based on the use of the fourth-order cumulants. Cumulants, which are high-order mixed moments, are widely used in signal processing problems (see, for example, [5]). For example, there are many methods for applying them to the problem of detecting the modulation type of a transmitted signal (see [6]). It was shown that cumulants have high efficiency in detecting the type of signal modulation. This motivated our study of the application of cumulants to the problem of detecting Carrier-in-Carrier signals.

This paper provides an algorithm for the classification of Carrier-in-Carrier signals using a fourth-order cumulants. To select the optimal decision threshold, we used the Area Under the Curve

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(AUC) criterion (see, for example, [7]). Numerical simulations confirm the effectiveness of the proposed method.

2. PRELIMINARIES

The mixture of two digitally modulated signals received by one antenna in a single channel can be expressed as:

$$x(t) = x_1(t) + x_2(t) + w(t),$$

where $x_u(t), u = 1,2$ are the signals from two sources:

$$x_u(t) = a_u e^{j\phi_u} \sum_{n=-\infty}^{\infty} s_u(n) g(t - nT_s - \tau_u), u = 1,2$$

and $s_u(n), u = 1,2$ are original sequences to be estimated; T_s is a symbol period; a_u are the amplitudes; ϕ_u are the phases; τ_u are the time shifts; $g(t)$ is a total channel response (assumed to be raised square-root cosine with known roll-off); $w(t)$ is a white Gaussian noise. Here we assume that the signals have the same symbol period, although we will comment below that the proposed approach can be applied to signals with different symbol periods. The principle of formation of the received signal is shown in Figure 1.

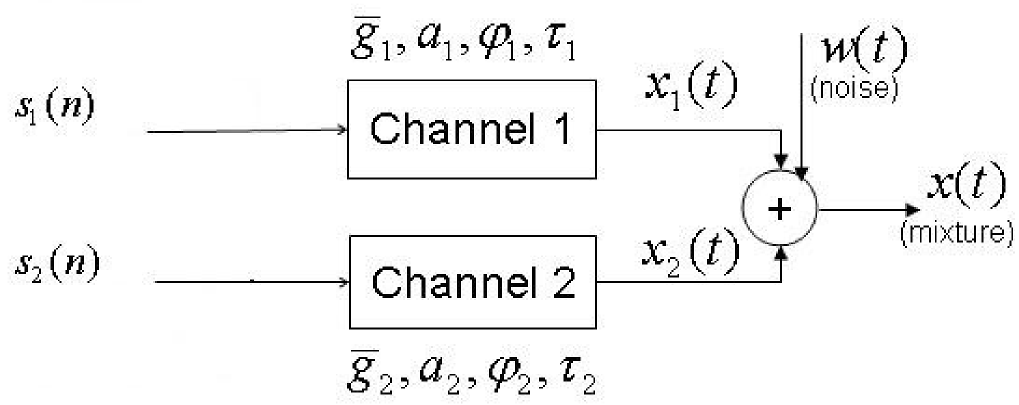

Figure 1: Statement of the problem.

The main criterion of the proposed method of detecting carrier-in-carrier in the channel is based on the demodulator's output constellation. Typical signal constellations of the QPSK (Quaternary Phase Shift Keying) and BPSK (Binary Phase Shift Keying) signals in the presence of noise with SNR (signal-to-noise ratio) equal to 10 dB are shown in Figure 2 (here $x_2(t) = 0$).

On the other hand, the carrier-in-carrier constellation has a distribution of points along circles around nominal points for simple QPSK (BPSK) modulation (Figure 3). This kind of constellation arises because of the sum of two M-PSK signals with a small difference of the carrier frequencies. The radius of the circle of distribution of points around the nominal point of the constellation depends on the ratio of the amplitudes of the signals, i.e. the greater the ratio of the amplitudes a_2 / a_1, the smaller is the radius of the circle (see Figure 4).

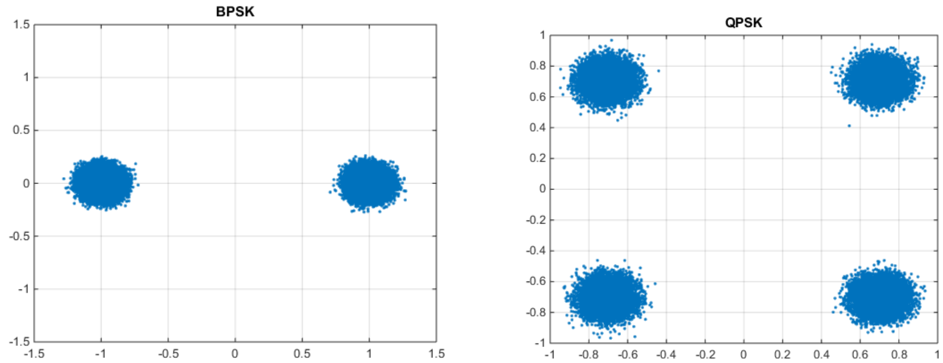

Figure 2: Output constellation of BPSK and QPSK signals

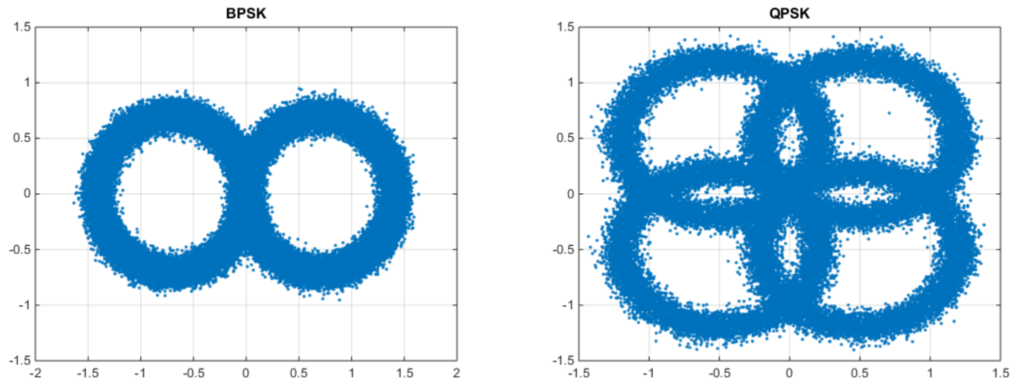

Figure 3: Output constellations for the sum of two BPSK signals and the sum of two QPSK signals with equal amplitudes

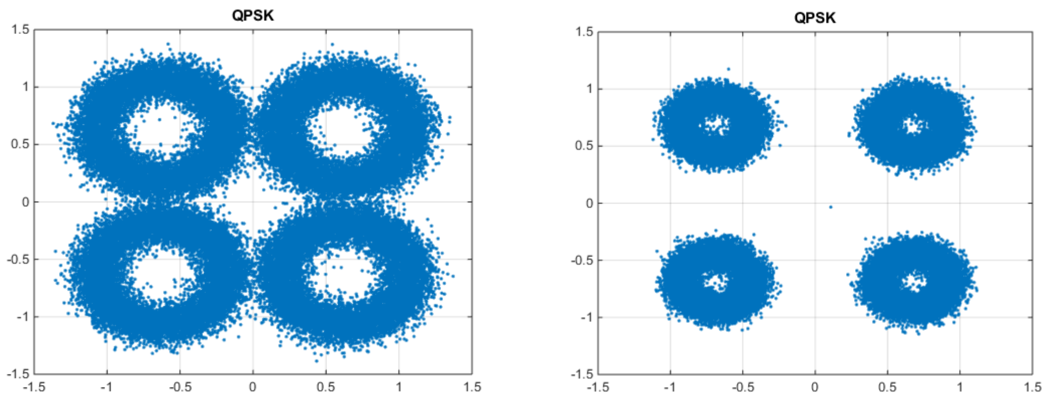

Figure 4: Output constellations for the sum of two QPSK signals with a ratio of amplitudes 2 and 4 respectively

Therefore, our proposed method for detecting Carrier-in-Carrier signals is based on detecting the transformation of the signal constellation. In accordance with this method, a fourth-order joint cumulant is calculated between the signal and its complex conjugate copy in one quadrant of the complex constellation.

The proposed detection algorithm is as follows. Signal samples are selected that correspond to one of the quadrants in the complex constellation (Figure 5):

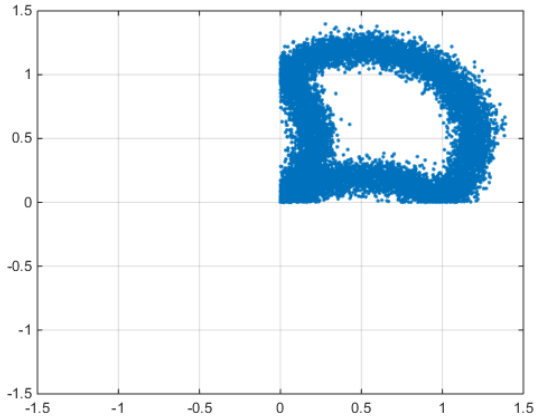

Figure 5: The QPSK samples corresponding to one of the quadrants of the complex constellation

Then the average value is subtracted from the received signal. Denote the received centered signal as $x(n)$. Then the value for the detection of Carrier-in-Carrier signals is fourth order cumulant:

$$C_{2,2} = cum[x, x, x^*, x^*], \qquad (1)$$

where x^* is the conjugated signal.

The proposed criterion for detecting Carrier-in-Carrier signals consists of comparing the cumulant (1) with a threshold value. In that case, if the value defined by formula (1) does not exceed the threshold:

$$C_{2,2} < \Pi_C, \qquad (2)$$

then a decision is made about the presence of a Carrier-in-Carrier signal. Otherwise, a decision is made about the absence of a Carrier-in-Carrier signal. The choice of the threshold will be discussed in the next section.

As is known, the quantity (1) can be expressed in terms of statistical moments:

$$C_{2,2} = E_{2,2} - |E_{2,0}|^2 - 2E_{1,1}^2,$$

where $E_{m,n}$ is the joint moment of the order (m, n):

$$E_{m,n} = \frac{1}{N}\sum_{k=1}^{N} x^m(k)(x^*(k))^n .$$

From here follow simple formulas for calculating of $E_{1,1}$ and $E_{2,0}$:

$$E_{2,0} = \frac{1}{N}\sum_{k=1}^{N} x^2(k),$$

$$E_{1,1} = \frac{1}{N}\sum_{k=1}^{N} |x(k)|^2$$

In addition, in this paper, we compare the proposed detection method with the approach based on the standard deviation of the average radius of the signal constellation points in one quadrant of the complex constellation. In accordance with this criterion, the standard deviation for the calculated distances $|x(n)|$ is calculated normalized to the square of their average value:

$$, \sigma_r = \frac{1}{e_x^2}\sqrt{\frac{1}{N}\sum_{k=1}^{N}(|x(n)| - e_x)^2} \tag{3}$$

Where

$$e_x = \frac{1}{N}\sum_{k=1}^{N}|x(n)|.$$

In accordance with this approach, in the event that the value σ_r defined by formula (3) does not exceed the threshold Π_r:

$$\sigma_r < \Pi_r, \tag{4}$$

then a decision is made about the presence of a Carrier-in-Carrier signal. Otherwise, a decision is made about the absence of a Carrier-in-Carrier signal.

3. Experimental Results

In the following experiments, the cumulant values (1) and the normalized constellation radiuses (3) were calculated for signal-to-noise ratios (SNR) from 0 to 10 dB with an amplitude ratio of 0 (case of a single signal, $x_2(t) = 0$), 1, 2, 4 and also for the additive white Gaussian noise. The results of calculating the parameter (1) are shown in Figure 6.

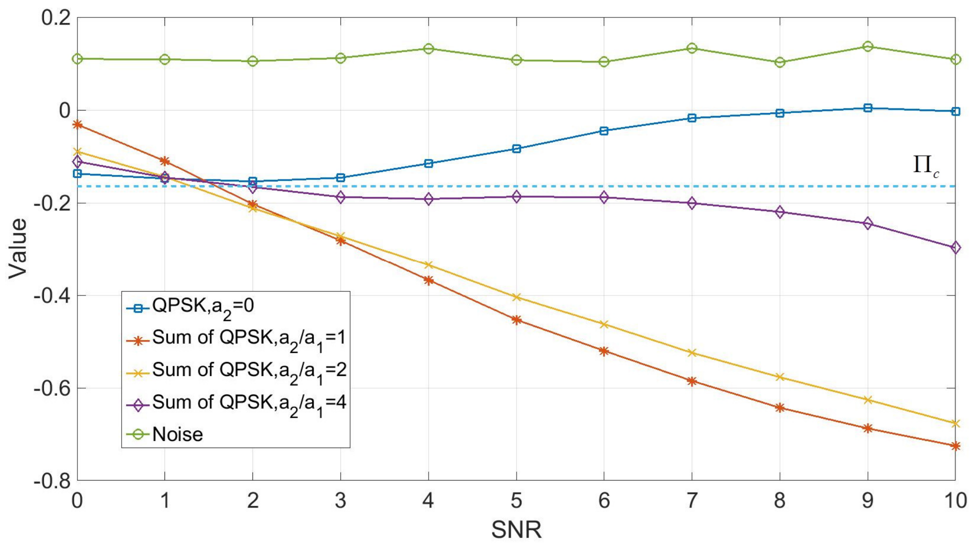

Figure 6: Dependence of cumulants on the SNR for various ratios of the amplitudes of the signals.

Figure 6 shows that the cumulant plots corresponding to Carrier-in-Carrier are separated from the plots corresponding to a single QPSK signal and background noise in the case when SNR is greater than 1.5 dB (which is a common situation in practice). The “cumulants” method ensures the correct detection of a Carrier-in-Carrier (by comparing with a given threshold) for different ratios of signal amplitudes. It can also be seen that the cumulant graph (1), corresponding to white noise, is clearly separated from the cumulant graphs corresponding to the three considered cases of the sum of QPSK signals.

The results of calculating the parameter (3) for the radius method are shown in Figure 7. As can be seen in the figure, the detector based on the constellation radius does not provide a clear separation of the radius values necessary for the correct detection.

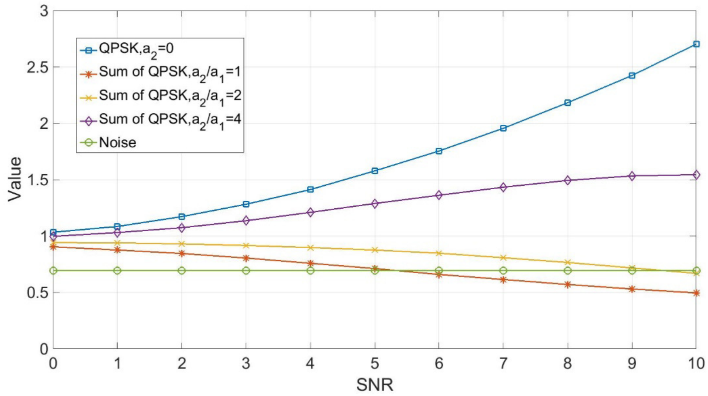

Figure 7: Dependence of normalized constellation radiuses on the SNR for various ratios of the amplitudes of the signals

In the next step, it is necessary to select the optimal thresholds for the rules (2) and (4). To select these thresholds and test the overall effectiveness of the proposed rule for detecting the Carrier-in-Carrier signals, we will use a technique based on the use of the ROC curve or, namely, Area under the Curve (AUC) parameter [6]. The calculation of this parameter requires the calculation of the statistical characteristics of a true positive rate (probability of correct detection) and a false positive rate (probability of false alarm) for all possible threshold values that lie within the range of values of the parameter selected as the detection criterion. The AUC plots for the cumulants method and the radius method are presented in Figures 8 and 9 respectively.

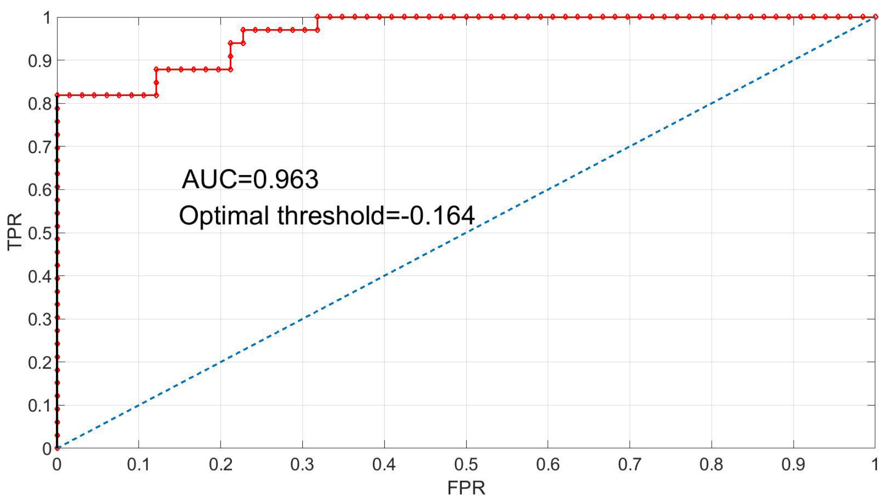

Figure 8: AUC for the cumulants method

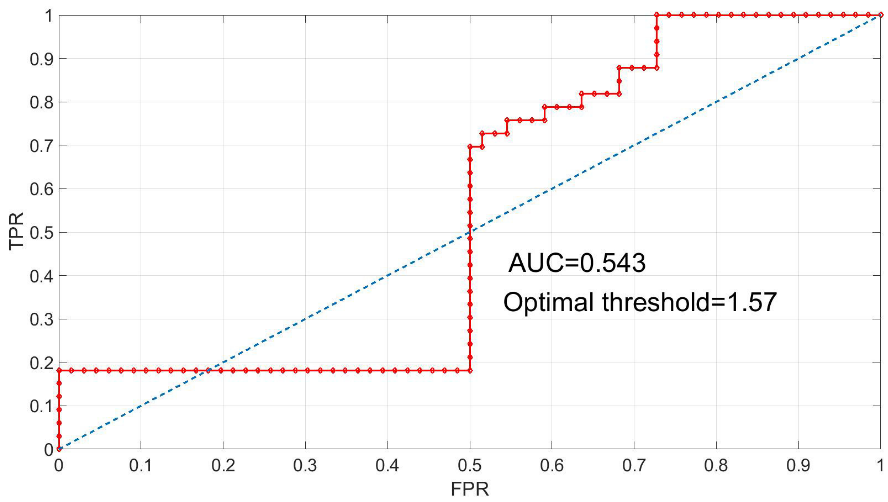

Figure 9: AUC for the radiuses method

From Figure 8 it follows that the AUC parameter for the cumulants method is 0.963, which indicates the high reliability of the proposed detection method. This is because the threshold $\Pi_C = -0.164$ chosen for the cumulants method is equally well suited for all SNRs and signal amplitude ratios. At the same time, the AUC value for the radius method (Figure 9) is significantly lower (0.543). The radius method is very sensitive to changes in the ratio of the amplitudes of the summable signals, as well as to variations of other parameters. Note also that the cumulants method showed high reliability when detecting the sum of signals with different symbol rates and other modulation types.

4. CONCLUSIONS

In this paper, a method for the detection of the Carrier-in-Carrier signals based on the calculation of fourth-order signal cumulants was proposed. In accordance with the methodology based on the "Area under the curve" (AUC) parameter, a threshold value for the decision rule was established. It was found that the proposed method provides the correct detection of the sum of QPSK signals with SNR greater than 1.5 dB, which corresponds to a wide class of practically encountered situations. The obtained AUC value for the cumulants method was 0.963, which indicates the high efficiency of the proposed detection method. The advantage of the proposed detection method over the "radiuses" method was also shown.

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AUTHORS

Vasyl Semenov received a Ph.D. in Acoustics from Institute of Hydromechanics of National Academy of Sciences of Ukraine in 2004. He is currently the chief of the Department of Algorithms at Delta SPE LLC, Kiev, Ukraine and doctoral student at the Institute of Cybernetics of National Academy of Sciences of Ukraine. His main research interests are in the fields of digital signal processing, demodulation, blind separation, and recognition systems.

Pavel Omelchenko received a Ph.D. in Mathematics from Institute of Mathematics of National Academy of Sciences of Ukraine in 2010. He is currently the member of the Department of Algorithms at Delta SPE LLC, Kiev, Ukraine. His main research interests are in the fields of digital signal processing, demodulation, blind separation, and cryptanalysis systems.

Oleh Kruhlyk received M.Sc. degree in Radioelectronics from the National Technical University of Ukraine "Kiev Polytechnic Institute" in 2017. He is currently the member of the Department of Algorithms at Delta SPE LLC, Kiev, Ukraine and Ph.D. student at the National Technical University of Ukraine "Kiev Polytechnic Institute". His main research interests are in the fields of digital signal processing, demodulation, and blind separation and methods.

CONSENT BASED ACCESS POLICY FRAMEWORK

Geetha Madadevaiah[1], RV Prasad[1], Amogh Hiremath[1], Michel Dumontier[2], Andre Dekker[3]

[1]Philips Research, Philips Innovation Campus, Philips India Ltd, Manyata Tech Park, Bangalore

[2]Institute of Data Science, Maastricht University, Maastricht, The Netherlands

[3]Department of Radiation Oncology (MAASTRO), GROW School for Oncology and Developmental Biology, Maastricht University Medical Centre+, Dr Tanslaan 12, 6229ET, Maastricht, The Netherlands

ABSTRACT

In this paper, we use Semantic Web Technologies to store and share the sensitive medical data in a secure manner. The framework builds on the advantages of the Semantic Web technologies and makes it secure and robust for sharing sensitive information in a controlled environment. The framework uses a combination of Role-Based and Rule-Based Access Policies to provide security to a medical data repository. To support the framework, we built a lightweight ontology to collect consent from the users indicating which part of their data they want to share with another user having a particular role. Here, we have considered the scenario of sharing the medical data by the owner of data, say the patient, with relevant people such as physicians, researchers, pharmacist, etc. We developed a prototype,which is validated using Sesame Open RDF Workbench with 202,908 triples and a consent graph stating consents per patient.

KEYWORDS (3-10)

Access Policies, Semantic Web,RDF/SPARQL, Role Based, Rule Based

1. INTRODUCTION

Learning healthcare systems aim to use information technology and data infrastructures to rapidly apply scientific insights to clinical care and to power scientific discovery from clinical insights [1,2]. For this to work, large amounts of routine health care and scientific data need to be made FAIR - Findable, Accessible, Interoperable and Reusable [3] - for both humans and machines. However, access to clinical data is longstanding challenge, particularly given the administrative, political and ethical barriers [4].

Ethical challenges often center on the need to protect the privacy of patients. One ethically and legally accepted way of accessing and processing personal data, such as patient data, is to ask consent of data subject involved [5]. Such consent must be specific. In the health care context, this means that patients should be able to control access to specific data elements to specific

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persons or machines for specific uses. Consent also needs to be dynamic as new data elements become available all the time and patients may change their minds and have a right to be forgotten in some jurisdictions [5]. On top of patient specific control, access policies may also be informed by institutional or national guidelines, like the USA HIPAA law [6], which defines specific data elements to be removed when data is shared with parties not involved in the direct care of patients, such as scientists. The Automatable Discovery and Access Matrix is an example of an initiative to encode such guidelines for consumption by machines [7]. Given these requirements, consent systems to get access to clinical data require a finely grained, multi-level (patient, institutional, etc.) and dynamic combination of authentication (which human or machine agent is accessing the data) and authorization (what data is accessed by which agent and for what reason).

Semantic Web technologies can be used to make data FAIR [8] and have been used as first implementations of a rapid learning health care system [9]. The Semantic Web, and its associated standards such as the RDF universal data model [10,11, 28], the SPARQL query language [12,13,25], and the OWL ontology language [14,15], aims to extend the Web from only consisting of human readable documents to a Web of machine understandable data [16]. However, the vision of the Semantic Web is mostly centered on open, linked data [17] so authentication and especially authorization have received relative modest attention.

The aim of this research is to develop a specific consent-based authorization scheme for clinical data using Semantic Web technology. We approached this by reviewing state of the art existing methods and techniques and comparing these with the method proposed by us.

2. RELATED WORK

Previous efforts in this domain include the work by Finin et al. [18] who represented a role-based control model into OWL. Their research focuses on the description of role concepts and their relationships (such as hierarchies).However, these investigators did not apply the roles in subsequent access on the Semantic Web. The author Büyükkılıç [24] discussed about rule-based control model, however the limitations of his work in the conversion of XML schema as per the standards.

Rishi KanthSaripalle et al.[27], have addressed the security and privacy at the knowledge level. They have proposed a Role Based Access Control Model to provide permissions to a RDF knowledge source. However, this approach would require administration and maintenance of roles and permissions by a knowledge/database administrator.

Gabillon and Letouzey[19] proposes to create security views on an RDF graph, similar to views managed by relational database administrators. In this approach, a graph is first created (using a SPARQL CONSTRUCT query) in which the security or access policy is applied. Subsequently, this graph is offered to the authorized user. They use a query based enforcement framework where each user specifies a rule for his existing RDF graph, which defines who can view the graph and what part of the graph can be accessed.

The drawback of their approach is that the query framework is cumbersome. It needs to be re-constructed for a new access, requiring maintenance by the graph administrator. In our use case, the patient maintains their own consent on data distributed across institutions and provides consent at multiple levels, eg consent for access of complete graph or consent for a node. Here, we build on the work of Gabillon et al. while addressing their limitations.

Sacco and Passant [20] present a lightweight ontology, the Privacy Preference Ontology to restrict access to a particular RDF data. The users have to first specify an access space indicating to which part of the data graph and to whom the restrictions have to be applied. Once the access space is defined, the users can specify the fine-grained access policies to the data belonging to a particular access space. For our use case, the limitations of such policies is that if there is modification in the dataset, almost all the rules have to undergo modification.

To address the shortcomings in the above solutions, a prototype of an access policy framework is presented which can be used by the institutions and organizations to share the sensitive RDF data, to specific agents having specific roles. The framework builds on the advantages of the Semantic Web technologies and makes it secure and robust for sharing sensitive information in a controlled environment.

3. METHODS

Consent Ontology and Graph

A consent ontology was analyzed by Gabillon [19] with which the consents of the user can be collected and stored, see **Error! Reference source not found.**. The classes in the ontology are

- Informed Consent Ontology (Consent Ontology): This is the main class that defines the framework for collection and storage of consents.
- Role: This class specifies the role of the user requesting the data and the user from whom the data is requested.
- AccessPolicy: This class defines the Access Policy defined by the users who would like share their data in a restricted way.
- Action: Refers to the type of Action that a user can be perform while requesting the data. The Action may be SPARQL QUERY or a SPARQL UPDATE.
- Consent: This class defines the consents under an access policy defined by the user.

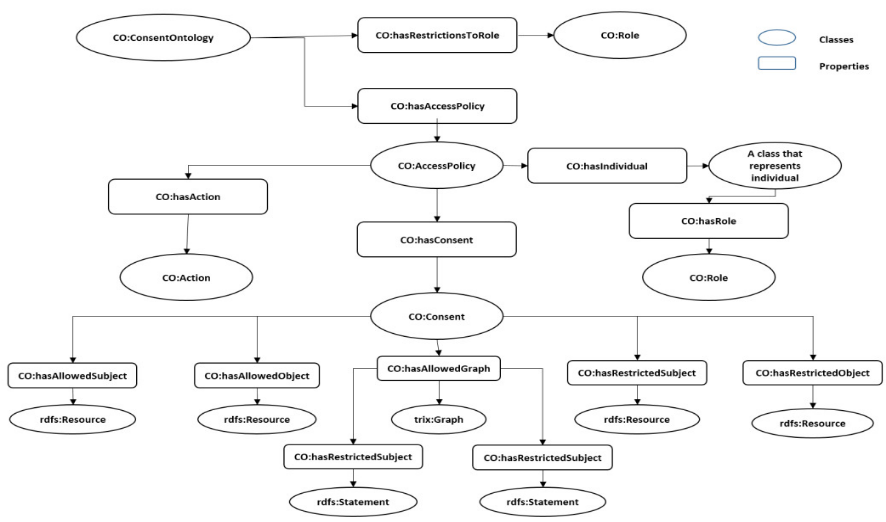

Figure 1: The consent ontology used in the access policy framework

The consent ontology was used to define the consent graph for a specific patient. First, roles were defined as instances of the class 'Role' rather than as subclasses, as is recommended by Fin in et al. [18]. Then an access policy is defined which includes the consents specified by a user for a given role. The specific consent specified in the example below which allows a researcher access to ICU data.

CO:ConsentOntology1 a CO:ConsentOntology ;
CO:hasRestrictionsToRoleCO:researcherRole.
CO:Access_Policy_1 a CO:AccessPolicy ;
CO:hasActionCO:Query ;
CO:hasConsent CO:Consent_1 ;
CO:hasIndividual<http://www.example.org/1> ;
CO:hasRoleCO:patientRole .
CO:Consent_1 a CO:Consent ;
CO:hasAllowedSubject<http://www.example.org/icu_data_1> .
CO:researcherRole a CO:Role ;
CO:hasAccess CO:Access_Policy_1.

Access Policy Framework

An access policy framework was developed to consume the above described consents and allow users access to the data given their roles (Figure 2). When a user (e.g. a researcher) logs in and requests data from a given patient or patient cohort, a SPARQL CONSTRUCT query is created which creates a subgraph of the original data graph. This subgraph is then shared with the researcher for querying. More specifically, the CONSTRUCT query is a federated SPARQL query across the data graph and the consent graph with a filter for the role of the user. We first query the consent graph with graph identifier consent Named Graph to obtain the consents. With the obtained consents from the consent Named Graph, we query the patient graph with graph identifier patient Named Graph to construct the graph with corresponding triples. Given below is the generic "patient To Researcher Rule" using which queries are constructed by replacing patient_name, patient Named Graph and consent Named Graph with the URL of a specific patient, her patient graph identifier and the consent graph identifier.

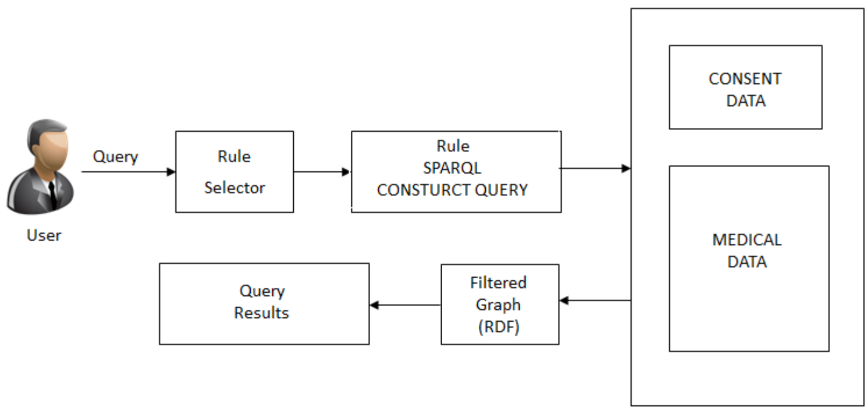

Figure 2 : Access Policy Framework

```
PREFIX BREASTCANCER: <http://breastcancer-data.org/>
PREFIX BREASTCANCERDOCUMENT: <http://breastcancer-data.org/document#>
PREFIX CO: <http://www.semanticweb.org/310204290/ontologies/2016/3/ConsentOntology#>
PREFIX sedi: <http://semantic-dicom.org/dcm#>
PREFIX EMR: <http://emr-data.org/>
PREFIX DICOM: <http://dicom-data.org/>
PREFIX DICOMDOCUMENT: <http://dicom-data.org/document#>
PREFIX EMRDOCUMENT: <http://emr-data.org/document#>
PREFIX GENETIC: <http://genetic-data.org/>
PREFIX GENETICDOCUMENT: <http://genetic-data.org/document#>
PREFIX GRAPHIDENTIFIER: <http://www.namedGraph.org/>
PREFIX ICU: <http://icu-data.org/>
PREFIX ICUDOCUMENT: <http://icu-data.org/document#>
PREFIX OCKR: <http://www.example.org/>
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX xml: <http://www.w3.org/XML/1998/namespace>
PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>
//Comments: Based on Patient Name graph and Consent Name graph, constructing the SPARQL Query to
define access policy
CONSTRUCT{ ?s ?p ?o. }

FROM NAMED<patientNamedGraph>
FROM NAMED<consentNamedGraph>

WHERE {
  {
   GRAPH<patientNamedGraph>
   {
VALUES ?s {OCKR:patient_name}
     ?s ?p ?o.
   }
  }
  UNION
{ // subgraph is shared with the researcher for querying
   GRAPH<consentNamedGraph>
   {
     ?consentontologyCO:hasRestrictionsToRole ?role.
FILTER(?role = CO:researcherRole)
     ?role CO:hasAccess ?accessPolicy.
     ?accessPolicyCO:hasConsent ?consent.
     ?accessPolicyCO:hasIndividualOCKR:patient_name.
   }
   {
     GRAPH<consentNamedGraph>
     {
      ?consent CO:hasAllowedSubject ?s.
     }
     GRAPH<patientNamedGraph>
     {
```

```
      ?s ?p ?o.
    }
  }
  UNION
  {   //query the consent graph with graph identifier consentNamedGraph to obtain the consents
   GRAPH<consentNamedGraph>
    {
      ?consent CO:hasAllowedSubject ?subject.
    }
   GRAPH<patientNamedGraph>
    {
      ?subject (!CO:)+ ?s.
      ?s ?p ?o.
    }
  }
  UNION
  {
   GRAPH<consentNamedGraph>
    {
      ?consent CO:hasAllowedProperty ?p.
    }
        //query the patient graph with graph identifier patientNamedGraph
   GRAPH<patientNamedGraph>
    {
      ?s ?p ?o.
    }
  }
  UNION
  {     GRAPH<consentNamedGraph>
    {
      ?consent CO:hasAllowedProperty ?property.
    }
   GRAPH<patientNamedGraph>
    {
      ?s ?property ?o1.
VALUES ?p {rdf:type}
      ?s ?p ?o.
    }
  }
  UNION
  {
   GRAPH<consentNamedGraph>
    {
      ?consent CO:hasAllowedProperty ?property.
    }
   GRAPH<patientNamedGraph>
    {
      ?s1 ?property ?s.
VALUES ?p {rdf:type}
      ?s ?p ?o.
    }
  }// construct the graph with corresponding triples
  UNION
```

```
   {
     GRAPH<consentNamedGraph>
     {
       ?consent CO:hasAllowedGraph ?graph.
GRAPH ?graph {?s ?p ?o.}
     }
   }
  }
}
```

The given query efficiently retrieves the allowed graph or a combination of allowed subjects and/or allowed properties for a single patient. In order to retrieve allowed graphs for multiple patients from a triple-store, multiple queries need to be constructed from the patientToResearcherRule and queried from the triple-store [25].

Before applying the access policies, the data of multiple patients is not stored in a single RDF graph. To enable retrieving data from multiple users, the complete data is partitioned into different datasets using named graphs. In this way, a graph identifier gets assigned to each triple, thus allowing easy retrieval of all triples belonging to a specific graph. Each dataset with a named graph has an owner who manages the data. In this case, each patient owns a RDF named graph.

4. EVALUATION

A number of real world use cases were used to evaluate the access policy framework. These use cases were

- A patient gives consent to the use of her birth data to a user with the role "Physician" but not to a user with the role "Researcher".
- A user with the role "Researcher" request the cohort of patients who have consented to the use of a combination of subjects such as EMR data, breast cancer data, ICU data, genetic data or the entire graph - patientNamedGraph.
- A patient gives consent to a specific named user with the role "Physician" but not to another named user with the role "Physician". (e.g. a patient may have a conflict with a certain physician)
- A patient gives consent but the data holder withholds consent (e.g. a patient may give consent to share a physician name with the outside world, which the hospital does not allow)

To evaluate if the access policy framework can fulfill these use cases a number of public datasets containing ICU, HIV and breast cancer data were used, (see Appendix and supplemental material). Using these we constructed 101 distinct patient graphs with 202,908 triples.

To specify the consents of all the patients, we randomly picked subjects and/or properties and/or and/or objects or the entire graph to be allowed by each patient and constructed the consent graph (815 triples, see supplemental material).

All data triples (n~200000) were loaded into Sesame OpenRDF-Workbench (version 4.1.2, Eclipse Foundation) on a Tomcat server (version 7.0, Apache Software Foundation). The evaluation was conducted on a computer with a processor (i5-4310-2GHz, Intel) and 8 GB of RAM. In each case, the SPARQL CONSTRUCT query consuming the consent ontology was executed first to obtain the filtered subgraph for each of the patients.

The procedure is as follows :

- The consent graph and patient graphs are loaded into the triple-store.
- Then a single query and retrieval is done for each patient graph leading to same number of queries as the number of patient graphs.

5. RESULTS

For the purpose of demonstrating our Access Policy Framework, we consider a RDF graph with a patient graph identifier as "ex:graph_patient1" and consent graph identifier as "ex:graph_consent" using synthetic medical data. Figure 3 and Figure 4 shows a RDF document of a patient with ICU acquired data, EMR data, genetic information, breast cancer data and Consent Ontology.

```
ex:patient1 a ex:Patient ;
  ex:has_breastcancer_data ex:breastcancer_data_patient1 ;
  ex:has_emr_data ex:emr_data_patient1 ;
  ex:has_genetic_data ex:genetic_data_patient1 ;
  ex:has_icu_data ex:icu_data_patient1 .

ex:breastcancer_data_patient1 a BREASTCANCER:Data ;
  BREASTCANCER:hasDocument ex:breastcancer_document_patient1.

ex:emr_data_patient1 a EMR:Data ;
  EMR:hasDocument ex:emr_document_patient1 .

ex:genetic_data_patient1 a GENETIC:Data ;
  GENETIC:hasDocument ex:genetic_document_patient1 .

ex:icu_data_patient1 a ICU:Data ;
  ICU:hasDocument ex:icu_document_patient1 .

ex:breastcancer_document_patient1 a BREASTCANCER:DOCUMENT ;
  BREASTCANCER:Age "66"^^xsd:string ;
  BREASTCANCER:PR-Status "Positive"^^xsd:string ;
  BREASTCANCER:Tumor "T1"^^xsd:string .

ex:emr_document_patient1 a EMR:DOCUMENT ;
  EMR:cost "211.66"^^xsd:string ;
  EMR:diagnosis "ENCEFALOPATIA NAO ESPECIFICADA"^^xsd:string ;
  EMR:responsible_physician "AA26E70"^^xsd:string .

ex:genetic_document_patient1 a GENETIC:DOCUMENT ;
  GENETIC:PR-Seq "CCTCAAATCACTCTTTGGCAAC"^^xsd:string ;
  GENETIC:PatientID "8"^^xsd:string ;
  GENETIC:RT-Seq "CCCATAAGTCCTATTGAAACTGTACC"^^xsd:string .

ex:icu_document_patient1 a ICU:DOCUMENT ;
  ICU:Heart_Rate_value 61 ;
  ICU:Respiratory_Rate_value 10 .
```

Figure 3 - RDF Document:ICU, EMR, genetic and breast cancer data

```
CO:ConsentOntology1     a                       CO:ConsentOntology.
CO:ConsentOntology1     CO:hasRestrictionsTo    CO:researcherRole.

CO:AccessPolicy1        a                       CO:AccessPolicy.
CO:AccessPolicy1        CO:hasIndividual        ex:patient1.
CO:AccessPolicy1        CO:hasRole              CO:patientRole.

CO:consent1             a                       CO:Consent.
CO:AccessPolicy1        CO:hasConsent           CO:cosent1.

CO:consent1             CO:hasAllowedSubject    ex:emr_data_patient1
```

Figure 4 Consent Ontology

We consider a scenario in which the medical data of a patient in a hospital has to be shared with a researcher. We evaluate our access policies for three different cases in which the consents of the patient given to a researcher are different. For each of the cases, the rules applied would the same as described in the METHODS section.

Case 1: Patient shares only the EMR data.

The consent graph for this case is shown in Figure 5, where the patient has allowed the subject ex:emr_data_patient1, which corresponds to the EMR data of the patient.

```
ex:emr_data_patient1 a EMR:Data ;
  EMR:hasDocument ex:emr_document_patient1 .

ex:emr_document_patient1 a EMR:DOCUMENT ;
  EMR:cost "211.66"^^xsd:string ;
  EMR:diagnosis "ENCEFALOPATIA NAO ESPECIFICADA"^^xsd:string ;
  EMR:responsible_physician "AA26E70"^^xsd:string .
```

Figure 5 Consent Graph EMR Data

Figure 6 shows the filtered graph obtained after the rule is applied on the consents and the patient data. The filtered graph is a sub graph of the patient data graph starting from the subject specified in the consents.

```
CO:ConsentOntology1     a                       CO:ConsentOntology.
CO:ConsentOntology1     CO:hasRestrictionsTo    CO:researcherRole.

CO:AccessPolicy1        a                       CO:AccessPolicy.
CO:AccessPolicy1        CO:hasIndividual        ex:patient1.
CO:AccessPolicy1        CO:hasRole              CO:patientRole.

CO:consent1             a                       CO:Consent.
CO:AccessPolicy1        CO:hasConsent           CO:cosent1.

CO:consent1             CO:hasAllowedProperty   ICU:Heart_Rate_value.
CO:consent1             CO:hasAllowedSubject    ex:breastcancer_data_patient
```

Figure 6 : Filtered Graph post application of consents

Case 2: Patients shares only heart rate in the ICU data and the Breast cancer data shown in figure 7.

```
ex:icu_document_patient1 a ICU:DOCUMENT ;
  ICU:Heart_Rate_value 61 ;

ex:breastcancer_data_patient1 a BREASTCANCER:Data ;
  BREASTCANCER:hasDocument ex:breastcancer_document_patient1.

ex:breastcancer_document_patient1 a BREASTCANCER:DOCUMENT ;
  BREASTCANCER:Age "66"^^xsd:string ;
  BREASTCANCER:PR-Status "Positive"^^xsd:string ;
  BREASTCANCER:Tumor "T1"^^xsd:string .
```

Figure 7:Heart rate in ICU Data and Breast Cancer Data

Case 3: Patient shares the complete data (Full graph)

Figure 8 shows the consent given by the patient to share the complete graph. There the complete graph with the specific graph identifier will be constructed as a result and shared with the researcher.

```
CO:ConsentOntology1     a                    CO:ConsentOntology.
CO:ConsentOntology1     CO:hasRestrictionsTo CO:researcherRole.

CO:AccessPolicy1        a                    CO:AccessPolicy.
CO:AccessPolicy1        CO:hasIndividual     ex:patient1.
CO:AccessPolicy1        CO:hasRole           CO:patientRole.

CO:consent1             a                    CO:Consent.
CO:AccessPolicy1        CO:hasConsent        CO:cosent1.

CO:consent1             CO:hasAllowedGraph   ex:graph_patient1
```

Figure 8 Patient Consent to share full graph

The total query execution time for all the patients was 111.64 seconds with 70,190 triples constructed as a part of subgraph or the filtered graph. The total query execution time refers to get all the filtered graphs for the patient in the triple store. The measurements shows a significant improvement over standard SQL based query and retrieve methods.

6. DISCUSSION

The framework uses a combination of Role Based and Rule Based Access Policies to provide security to a medical data repository. The prototype is validated using Sesame Open RDF Workbench with 202,908 triples and a consent graph stating consents per patient. The main advantage of this Access Policy being, there is no requirement for each user to specify the rules. The user will only have to provide the consents. The rules can be specified by the Central

Authority or an Administrator who takes care of the medical database. The rules are specified according to the structure of the data, irrespective of the consents given by the users.

Various authors have presented their work on access policies for the sensitive RDF data. Finin et al. [18] integrated RBAC (Role Based Access Control) model into OWL. They used OWL ontologies to represent RBAC model which specifies the access control policies. Gabillon and Letouzey[19] emphasize on providing access control policies over named graphs and views which generates a subgraph. They use query based enforcement framework where each user specifies a rule for his existing RDF graph, which defines who can view the graph and what part of the graph can be accessed. Sacco and Passant [20] present a light weight ontology, Privacy Preference Ontology(PPO) to restrict access to a particular RDF data. The users have to first specify an access space indicating to which part of the data graph and to whom the restrictions have to be applied. Once the access space is defined, the users can specify the fine-grained access policies to the data belonging to a particular access space. The limitations of such policies is that if there is modification in the dataset, almost all the rules have to undergo modification.

K. Mohan and M. Aramudhan[21] have defined access policies using ontology-based approach, where they consider Object and Data properties for providing a secure access to personal health data stored in the cloud. They have not addressed the workflow of who generates the rules and the approach lacks a role based approach which makes it easier to define the access policies for healthcare data.

In [22] Hannes Muhleisen et al. define PeLDS (Policy enabled Linked Data Server), where they partition the dataset into different named graphs and create temporary view on those graphs by defining rules. The rules are defined using SWRL (Semantic Web Rule Language). Each rule from the access policy is attributed with an additional consequence to add the rule identifier to a global list of matched rules. If such a rule matches due to sufficient access rights for the current user, it will be added to this list. The list of rules is evaluated, and for every triple matching the data classifications contained in the rules consequence predicate list is copied from the dataset to the result graph. Rules depend on the structure of the dataset where a view of the graph is obtained and in case the structure is changed, all the rules have to be modified accordingly. The framework can further be extended to other types of data such as DICOM data converted into RDF format [23, 29].

However, in each of the approaches, users have to define their own rule which becomes cumbersome and difficult to manage. Also, in organizations like hospital, if each patient defines their own rules, it leads to duplication of the rules since the structure of the dataset remain the same. Instead, a single rule can be defined for all the patients with only customizations in consents.

7. CONCLUSION

We built a lightweight ontology to collect the consents from the users indicating which part of their data they want to share with another user having a particular role. Here, we have considered the scenario of sharing the medical data of a hospital amongst different roles like a patient, physician, and a researcher. We have followed a hybrid approach with a combination of Role-based and Rule-based Access to provide security to a medical RDF data. A central authority, knowledgeable in semantic web and the database construct the rules, and the patients provide the consents. The advantages of our policy framework is that if a user wants to change the access rights, only the consents need modification. If the dataset is updated, only the rules specified by central authority requires modification.

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AUTHORS

Geetha Mahadevaiah, Senior Director at Philips, Research Department, PIC, Bangalore. 30+ years of experience in software engineering and management. Bachelor of Engineering in Computer Science and Technology (1985) Bangalore University Master of Business Administration (Finance) (1994),Bangalore University

Prasad R V, Program Manager and Team leader at Philips, Research Department, PIC, Bangalore. 19 years of experience in Healthcare domain, Healthcare Software Development. Bachelor of Engineering in Mechanical (1995), Bangalore University Masters in Science by Research (1999), Indian Institute of Science, Bangalore

Amogh Hiremath, Was a Senior Research Engineer at Phillips, Research Department, PIC, Bangalore between 2016 and 2018 Bachelor of Engineering in Electronics (2014), VTU Masters of Technology in Communication Engineering (2016), NIT Suratkal Currently PhD Candidate at Case Western Reserve University, Cleveland, Ohio

Michel Dumontier is a distinguished professor of data science at Maastricht University and head of the Institute for Data Science, connecting data science initiatives and projects from all faculties. He is also deeply involved in the FAIR data approach (Findable, Accessible, Interoperable, Reproducible).

André Dekker is a professor of clinical data science at Maastricht University and has been leading the development of prediction models in radiation therapy for many years. He is also coordinator of the Personal Health Train project, aiming to facilitate citizen science.

DYNAMIC HUMAN-CENTERED DESIGN: REINVENTING DESIGN PHILOSOPHIES FOR ADVANCED TECHNOLOGIES

Te-Wei Ho[1],Timothy Wei[2], Jing-Ming Wu[1], and Feipei Lai[345]

[1]Department of Surgery, National Taiwan University Hospital and National Taiwan University College of Medicine, Taipei, Taiwan
[2]Department of Cognitive Science, University of California San Diego San Diego, California, USA
[3]Graduate Institute of Biomedical Electronics and Bioinformatics, College of Electrical Engineering and Computer Science, National Taiwan University, Taipei, Taiwan
[4]Department of Computer Science and Information Engineering, College of Electrical Engineering and Computer Science, National Taiwan University, Taipei, Taiwan
[5]Department of Electrical Engineering, College of Electrical Engineering and Computer Science, National Taiwan University, National Taiwan University, Taipei, Taiwan

ABSTRACT

As technology becomes more advanced and saturated in various industries, the role of design becomes equally significant. Traditionally, human-centered design (HCD) has been the main creative approach for the design decisions in numerous applications. However, the role of HCD within the technology raises concerns. This paper examines the design philosophy of the HCD in parallel with rising technologies, specifically artificial intelligence and machine learning systems, and explores the implications of utilizing a more dynamic approach. With HCD, much of the considerations are determined through user research; the dynamic HCD approach is introduced to accommodate the different units of analysis presented by advanced technologies to create more streamlined designs that support and accelerate technological innovation.

KEYWORDS

Human-computer interaction, human-centered design, artificial intelligence

1. INTRODUCTION

Technology is at a critical point where improvements result in significant effects on real-world applications. With advancements such as artificial intelligence (AI) and machine learning paired with big data and analysis, most of the current technologies will drastically change in the future. Such examples include assistance software such as Amazon's Alexa, Apple's Siri, or Google Home; introduction and competition to perfect autonomous vehicles; and reformation of healthcare operations, procedures, and equipment. The role of design is similarly becoming equally significant; however, these technologies are not fully utilized unless they are provided to the users in a practical manner [1].

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In exploring design directions, the human-centered design (HCD) is one of the most widely adopted creative approaches used by various industries. As the role of the HCD is evaluated against today's technology, the related concerns become more apparent. This study explores these shortcomings and offers solutions that address the ever-changing nature of technology. The present research aims to expand on the current design philosophies to go further than designing for a single part (i.e. the user) and considering all the factors and units of analysis. Such action is reasonable, because given our understanding of cognition and the theories of how human cognition works, we rely heavily on all parts of a culturally-complex system. Considering just the user is insufficient; instead, we must explore the interactions among all agents of the system [2]. Not only will this research examine the user to improve the lifestyles and economies from accelerated innovation, it will also provide more accurate and streamlined use of the products through removal of bias and explain ability, as described later.

2. HUMAN-CENTERED DESIGN

2.1. Role

Don Norman introduced the HCD approach as a solution to the repetitive problems faced by new technologies and applications. Norman stated that, "HCD puts human needs, capabilities, and behavior first, then designs to accommodate those needs, capabilities, and ways of behaving." [3] HCD is therefore a design philosophy that was created to focus on user needs. HCD has also apparently aided the industries of today: products have been refined or redesigned with improved user flow. The design and use of technology matter just as much as the functions themselves.

Although a fairly commonplace approach for much of the designs, the HCD can be subliminally observed in numerous applications today. In technology and product applications, any design direction that emphasizes and utilizes user research and analysis is essentially applying the HCD. For example, the smart phone gestures and functions are programmed according to the abilities of the user and the affordances of the device. The Figure 1 shows examples of common finger gestures for smart phone applications. These examples are designs that use the HCD approach by accommodating affordances of the device and abilities of the user.

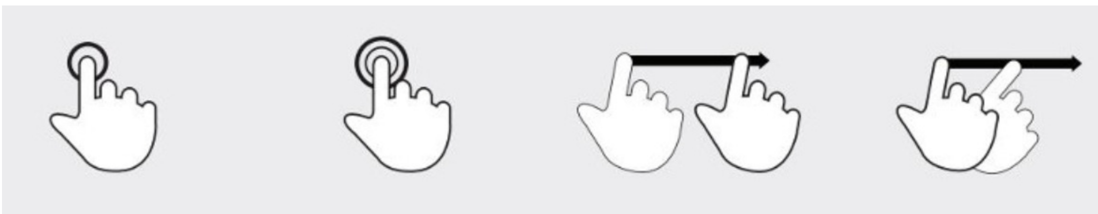

Figure 1. Example of common finger gestures for smart phone applications.

In terms of the interface design, the weight is shifted more for the operators and decision-makers to reduce the human errors. Examples include the cockpit displays. Other examples include the areas of decision-making or operating procedures, as observed in command center areas for military personnel or dispatch centers. The basic planning for situations is considered with the users in mind (who will take part in the decision-making?) and determining their needs (what do they need to know?). The Figure 2 shows the navigation team aboard a navy. The bearing recorder is in the foreground. The plotter is to the left. The interaction among the people on the team is a result of the HCD approach from the planning and operating procedures [4].

Figure 2. Navigation team aboard a navy.

2.2. Shortcomings of the HCD

When the HCD is applied to technologies such as AI, various existing implications can result in negative outcomes. Although the HCD is practical in the sense that it is a design philosophy that can be applied to various industries, it is also constrained by that very idea; Norman referred to this condition as hitting the local maxima, that is, not knowing how to adapt beyond the user [5]. When reflecting on the HCD on applicable technologies today, the concerns may include the following:

(1) The HCD may provide the users with what they want, but this step may not necessarily be the most optimal improvement. In the past, technology was simple enough with a limited understanding sufficient for use. In those cases, the challenge for users lay more on the user journey and interaction. With technologies such as AI, the users face difficulty in comprehending their potential. Therefore, the intelligent agent needs to be technically designed without the extreme consideration for the users. In this manner, HCD and its reliance on the user research and analysis inherently constrains the technology itself.

(2) An imbalance exists between the users. Considering all the users for features or products—essentially the units of analysis in terms of distributed cognition—the values and differences among the users are inexplicable. For example, for a product, the users may include the general consumers, businesses, clients, and shareholders. With cases regarding AI, long-term goals and business decision-making might be more beneficial than centering around the general consumers. Therefore, the units of analysis expand to strategy, economic benefit, and company influence. In the industry, a perpetual struggle exists between the designers and players, such as the engineers or corporate stakeholders. This situation is a concern that influences design direction.

(3) The HCD focuses not on augmenting technology nor inhibiting innovation. That is, we do not say that a human-centered approach is fallible, but rather that it may be inadequate. With HCD, the focus on its users deviates the attention from the technology itself. As the designers focus more on iterating the interactions between humans and computers, equal efforts must also be spent on improving the technology. For advanced technologies, such as AI, HCD may be a limitation to the maximum potential of the intelligent agent.

(4) The HCD is very much based on past experience and interpreting the future based on these past ideas. When paired with big data and analysis, the focus on these things indicates that the designers are constantly correcting past problems; they rely on past records to determine the future. Although correcting the problems necessarily improves the products, the designers should also consider the future implications of their designs. Much of this concern

originates from the understanding of technology and making decisions according to the technology and not the users.

(5) The HCD considers empathy and designs for the emotions of the users but fails to inspire unique qualities for the technology itself. This consideration is not much of a concern than it is an inconsideration of the true values of advanced technology and what it offers for the users. The bounds of technology should not only be explored but also examined in a manner that makes the technology unique.

An example of the limitations of the HCD can be observed in Apple Health, a health monitor and fitness tracking application. Here user data is gathered but not explained; generic and short videos which relate to a patient's overall health are shown instead. However, the patients are not individually assessed. For example, one video focuses on the activity and how exercise benefits the body but fails to address the particular individual’s needs. What if the specific user suffers from medical or physical conditions that render him or her incapable of exercising? The videos would fail to supply practical information. The Figure 3 shows examples of a health monitor application that fails to provide explanations according to the patient data.

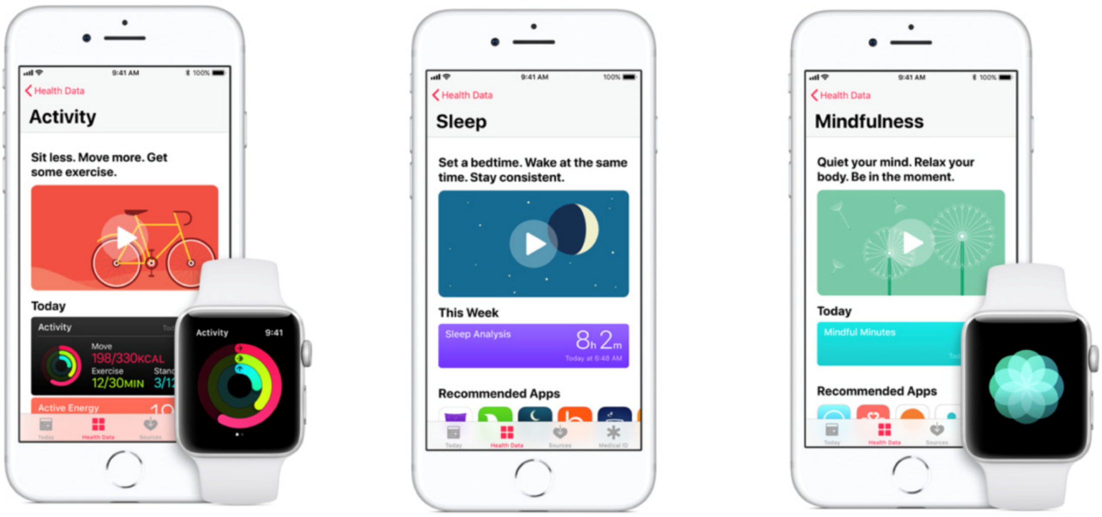

Figure 3. Example of a health monitor application.

The advanced technologies, such as AI and machine learning, can use gathered data to determine the best approach for such specific individual. However, failing to consider technology as a unit of analysis, the design of the product may not provide the user with the most optimal solutions.

If the AI played a greater role in the development and design of Apple Health, the application itself would be able to recognize user limitations, per his or her medical history and current state (through vital signs), and use the analysis to provide the individuals with a more tailored solution to improve user health.

3. DYNAMIC HUMAN-CENTERED DESIGN (DHCD)

3.1. Authors

The DHCD provides an improved approach for the concerns of the HCD. By focusing not only on the users themselves but also considering the potential of technology, the designers can remove the limitations otherwise presented. DHCD is less about shifting from a user-centered approach than simply but deeply examining all the elements of the advanced technology. The question transforms from, “What do users want?” into “How do we augment the lifestyles of all users while best considering the abilities of the product?”

The implications of refining this approach would mean accelerating innovation and deeply considering otherwise big-picture concepts, such as long-term economic stimulation and empowering human civilization. The specific changes may include removing bias from the data from artificially intelligent agents or improving the explain ability by interpreting the analysis in a more functional and correct way, as described in Section 4.

3.1. Theories of cognition

The development of the DHCD approach originates mainly from the theories of cognition such as the en activist view and distributed cognition.

3.1.1.Enactivist view

The en activist view argues that cognition arises from the dynamic interaction between an acting organism and an environment [6]. If the users are the acting organisms, the environment may consist of tools and cognitive artifacts, which are designed for the users themselves, in place today. These artifacts deeply impact user cognition and therefore shape interaction and future development [7]. Several artifacts may be internal or external representations and may be considered as currently existing technology, including something as simple as a hammer or prescription glasses. AI would also be considered another representation. With this logic, when designing and reshaping the technology for what it is, one must absolutely consider more than the users as acting organisms and also infer on the environment and the products and technology available because these factors directly affect the human cognition [7].

The interaction between the acting organisms and their tools and artifacts rest on the concept of affordances—what the objects provide, offer, or furnish—for the organism, for good, or for ill [8]. These affordances influence design decisions. In terms of the technology, understanding these affordances comes from a deeper knowledge of the potential of these advanced technologies.

3.1.2.Distributed cognition

The DHCD approach may very well be an expansion on the ideas of Edwin Hutchins regarding distributed cognition. The fundamental premise of distributed cognition involves the idea that cognition emerges from the interactions among the elements of complex systems [4]. Although the HCD relies on the acting organism side of enactivism, the DHCD’s role lies in its considerations for these elements. The Figure 4 shows an example and model of distributed cognition as represented by the cognitive scientist Taylor Scott.

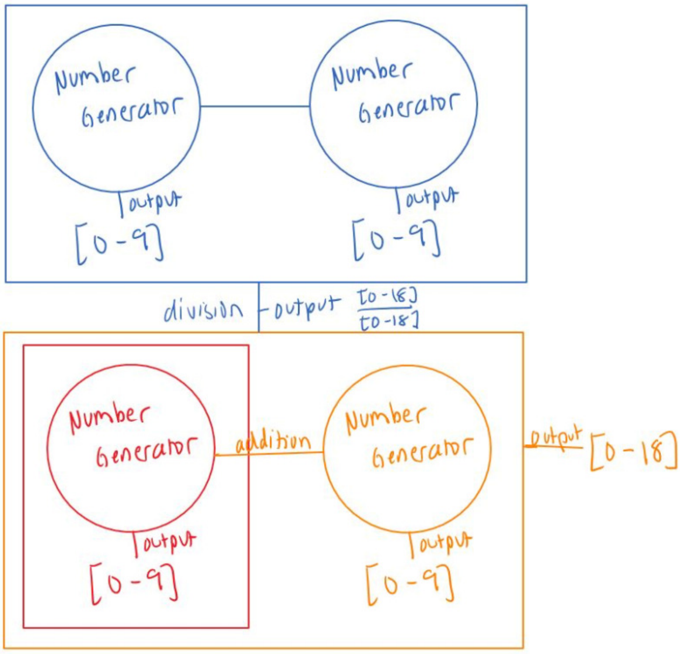

Figure 4. An example and model of distributed cognition.

The above representation presented by the cognitive scientist Taylor Scott from the University of California, San Diego, illustrates the benefits of utilizing the distributed cognition framework for applications other than the individual unit of analysis.

David Kirsh, a pioneer of distributed cognition, stated that, "If we can understand how individual people engage their environments, how they appropriate artifacts, how they rely on material aspects of their activity space to help them stay in control, to manage thought, perception, and choice, then perhaps we can begin to put these individuals together into larger socio-technical systems" [9].

The cognitive artifacts that make up our socio-technical systems all contribute and influence culture and thought [10]. By considering these factors, we can find useful qualities in various agents and alter them to influence the design and planning of future technologies. Hutchins [11] and Marvin Minsky [12] also support this notion by proposing a direct consideration from the extended mind to cognition in cultural–cognitive ecosystems [13].

3.2.Value-based approach

The DHCD should contain variable weights that determine the true value of each element considered during the design process. Thus, the areas emphasized by the DHCD would differ for each project. For example, in terms of user interface design, more weight may be put on understanding user psychology and preferences. For AI, more weight might better serve the analysis, interpretation, and explain ability of data.

To expand on this approach, storytelling becomes heavily important for artificial intelligent agents. These agents rely on specific datasets to accomplish accurate outputs. However, the outputs are rendered useless if the information cannot be conveyed in a meaningful way. In this way, the DHCD allows the designers to not only focus on the users but also on interpreting the data that are most similar to the conclusions.

4. DHCD APPLICATION TO AI

4.1. REMOVAL OF BIAS

When applied to advanced technologies, such as AI or machine learning, the DHCD expands the units of analysis from distributed cognition and provides significance to elements such as bias in data.

As the accuracy of AI output is hugely based on data, the data selection becomes fundamental in determining the overall direction. Each selection of data infers certain biases depending on the product goals. For HCD, the approach would be to determine the data points that yield higher accuracy according to the user needs. However, this condition increases bias and although it may sufficiently provide for what the users want, it may not be helpful for the goals of the company or the lifestyles of the users.

For example, when applying AI in the healthcare industry, a product may be available to predict future medical risks for obese individuals. This application will be based on a variety of selected data, such as the individual's weight, health and fitness levels, vital signs, family history, and medical history. However, the data selection includes bias for these individuals when determining the medical risk.

If a certain level of medical risk is determined, then the risks are based solely on these factors alone when truthfully, risks for obese individuals may also depend on demographics, environmental conditions, and workplace stress levels, to name a few. These factors may be the outside bounds of the user but may heavily impact the goals of the product. The DHCD aims to empower AI by considering the ideas outside of the unit of analysis of the user in industries such as healthcare [14].

4.2. Increased explain ability

The concept of explainability is another potential solution when applied to AI. As the designers need to create representations that convey the information the artificial intelligent agent produces, the information should not be lost in translation and should be insightful.

Simply sharing an output is insufficient because such action may not result in a direct effect on the users. Instead, the analysis and interpretation of the information provide users insights into their understanding of the product.For example, an application regarding obesity and medical risk, insights would interpret all data points, provide an assessment, and also advise the user on how to improve the individual's lifestyles in a way that addresses the specific category of the data at fault. A specific instance of this example might be that an individual's increased medical risk is due to environmental factors, such as air quality and stress level. An HCD approach might simply advise the user that these factors may distress the physical condition of the individual. A DHCD approach would not only evaluate this condition but also explore methods that would truly aid the individual, reinforcing the storytelling aspect and essentially designing for what the users need and not what they want. Emphasizing the variables that are more or less outside the domain of the user may improve the user's situation. The design of representations must be considered when utilizing AI [15].

4.3.Example of a the DHCD approach in complex systems with data-driven technologies

When considering the design approach for the National Taiwan University's Medical Bioinformatics Lab, DHCD is valuable when determining the direction for the Precision Medicine project. With the ultimate focus on utilizing data for analysis and implementing AI and machine learning to predict medical risk and assessment, the significance of the project lies not only on the user journey and how the technology is used but more on how the analysis obtained from the AI evaluations are used to determine the results. For example, this approach was considered when prototyping the user interface of a dashboard for caregivers (Figure 5).

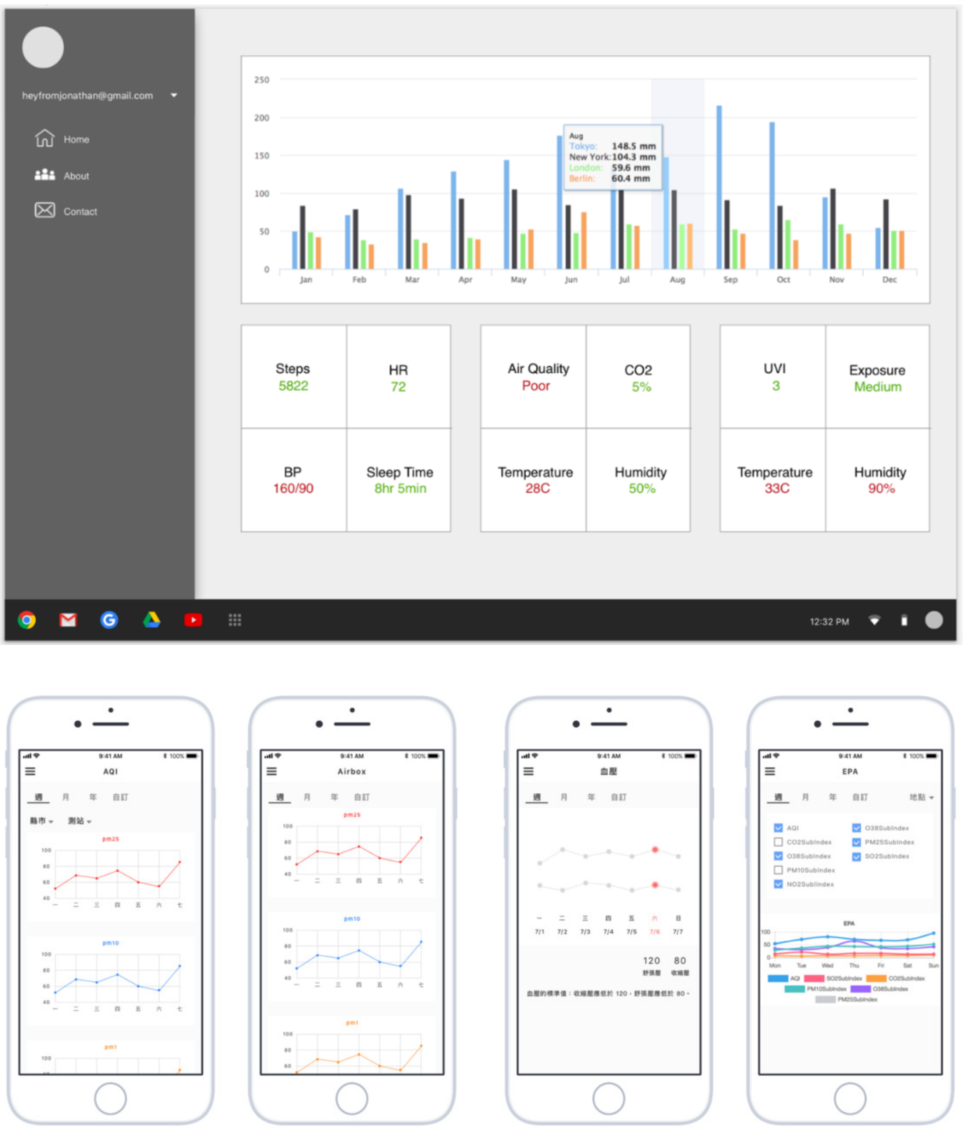

Figure 5. Example dashboard design that utilizes DHCD.

In the user interface prototype shown in Figure 2, the analysis is represented in a way that supports the correlations drawn from the data gathered. By using interactive buttons, charts, and graphs, the user data are retained and the user journey remains efficient and human-centered. As for the medical risk and prediction, the user can easily determine where the risk might originate according to the color schemes.

The achievements of modeling user experience and interface from the considerations of the DHCD include the streamlined use of web applications. Sorting through datasets becomes easier with more interaction, where correlations and trends are more easily recognized. The economic implicationsshould also be recognized. The caregivers and healthcare workers are more available to attend to patients instead of managing their collected information, including vital signs and medical history. This type of work is replaced by intelligent agents that can collect and analyze data. Future implications regarding artificial intelligent work concern accuracy and how, by considering all the factors of data, the artificial intelligent agents can increase their accuracy in predicting medical risk.

5. CONCLUSION

The DHCD approach aims to shift the design philosophies for players in the technology industry to accommodate advanced technologies. By exploring the role and concerns of the HCD and evaluating them against the theories of cognition, we determine the importance and methods of how to feature the technology in way that augments user lifestyles. This importance creates a more dynamic approach - one that considers all elements within a system and assigns weights accordingly - to shape the product into something that supports and augments human life. Although the HCD approach is sufficient to perfectly apply technology, new considerations must be explored when advanced technologies are involved.

ACKNOWLEDGEMENTS

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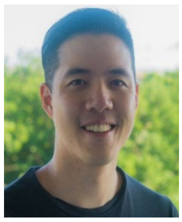
AUTHORS

Dr. Te-Wei Ho got his PhD degree from the Graduate Institute of Biomedical Electronics and Bioinformatics at the National Taiwan University in June 2016. He got honors of Annual Best Doctoral Dissertation Award of Biomedical Electronics and Bioinformatics Camp of National Taiwan University in 2016, 6th Honorary Award of Biomedical Electrical Engineering Reward Research and Innovation of National Taiwan University in 2016, 5th Honorary Award of Biomedical Electrical Engineering Reward Research and Innovation of National Taiwan University in 2015, IT Student Leader Award of Institute of Information & Computing Machinery in 2014, 11th National Innovation Award from Institute of Biotechnology and Medicine Industry in 2014. He was the 20th member representative of Institute of Electrical and Electronics Engineers (IEEE) Taipei Section in 2017.Regarding his research achievements, as of 29January2019, he has published 20 journal papers, 37 conference papers, and 1 textbook. He was invited as reviewer by major academic journals such as Journal of Medical Internet Research, PLoS One, Medicine, Journal of Medical Systems, Transactions on Neural Systems and Rehabilitation Engineering, Sensors, Computers & Electrical Engineering, and so on. He also has several patents for the augmentation technologies in terms of automatic electrocardiogram interpretation, image processing for wound, and wearable device application. His current research interests include clinical informatics, big data in health and health care, and electronic health records.
Personal website: http://orcid.org/0000-0002-4371-6936



Mr. Timothy Wei is an undergraduate student at University of California San Diego, studying Cognitive Science, Human-Computer Interaction. He has worked with the Biomedical Informatics Research at National Taiwan University to develop user interface and user experiences. He has also worked on multiple projects concerning usability and information architecture, and interaction design. His project on solving medical non-adherence was a finalist at MedHacks, a hackathon focused on the healthcare industry. His interests include understanding the theories of cognition, mainly in embodied and distributed cognition, and how advanced technologies may shape our environment.

Dr. Jin-Ming Wu received his M.D. at the National Taiwan University in 2003. He completed general surgical residency and was the administrative Chief Resident at National Taiwan University Hospital in 2010. He earned the Ph.D. at Graduate Institute of Biomedical Electronics and Bioinformatics in National Taiwan University focusing on both development of telecare on surgical patients and data-mining on electronic medical records. Now he is a clinical assistant professor in National Taiwan University of Medicine.

Personal website: http://ah.ntu.edu.tw/web/Teacher!one.action?tid=106

Prof. Feipei Lai received a B.S.E.E. degree from National Taiwan University in 1980, and M.S. and Ph.D. degrees in computer science from the University of Illinois at Urbana-Champaign in 1984 and 1987, respectively. He is a professor in the Graduate Institute of Biomedical Electronics and Bioinformatics, Graduate Institute of Medical Device and Imaging, Graduate Institute of Health Policy and Management, Department of Computer Science & Information Engineering and the Department of Electrical Engineering at National Taiwan University. He also serves as secretary in medical affairs at National Taiwan University Hospital. He was also a guest Professor at University of Dortmund, Germany and a visiting senior computer system engineer in the Center for Supercomputing Research and Development at the University of Illinois at Urbana-Champaign. His current research interests are Medical Informatics and Medical Information System. He is one of the founders of the Institute of Information & Computing Machinery and served as the President during 2009/7-2013/7. He published 132 journal papers, 236 conference papers, and 5 text books currently.
Personal website: http://ah.ntu.edu.tw/web/Teacher!one.action?tid=2140

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ON-LINE OPTIMIZATION METHOD FOR ENERGY EFFICIENT PUMP-STORAGE OPERATION WITH INTEGRATED FILLING TIME CONSTRAINT

Thomas Hieninger, Florian Goppelt and Ronald Schmidt-Vollus

Nuremberg Campus of Technology, TH Georg Simon Ohm, Nuremberg, Germany

ABSTRACT

This contribution presents a Nelder-Mead based on-line optimization algorithm for centrifugal pumps to decrease the energy demand for filling tasks during operation. This method works with power and filling level data, which adapts the rotational speed to the current filling level. During optimization, rotational speed constraints have to be regarded to fulfill a steadily filling within a maximum permitted time. To develop and to test the algorithm, a model of a pump system is used, which is implemented in Matlab/Simulink. The tuning method achieves energy savings at the permitted filling time.

KEYWORDS

Online-Optimization, Centrifugal Pump, Energy Efficiency, Fluid Storage

1. INTRODUCTION

A primary application for electric motors with a share of 19 percent is the operation of centrifugal pumps. This widespread distribution leads to nine percent of the worldwide electrical energy demand [1]. An essential task of pumps is to fill storages, which may occur in water distribution systems or industrial plants.

Two different effects have to be focused on to increase the energy efficiency of filling processes. First of all, the best efficiency point is not necessarily the most efficient operating point for filling storages. The speed should be lowered to avoid dynamic losses, whereas the resulting part load leads to lower efficiencies. Secondly, the operating point moves depending on the increasing head during the filling process. Therefore, a clearly defined solution is not available, which can be solved by employing an optimization algorithm (OA).

An approach with a volume flow meter is described in [2]. Another way is to adapt the rotational speed to the current filling level to avoid additional losses and costs due to the flow meter [3]. The authors in [4] showed a method and the potential energy savings employing a filling control strategy. The strategies in [3] and [4] leads to the additional issue, that the filling time of an energetic optimized storage system can be significantly extended. Thus, a set-point for maximum filling time may be necessary, depending on the application.

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It is also a problem that the real behavior can vary from the behavior according to the data-sheet given pump characteristics and the calculated plant characteristic. This deviation leads to the approach that the frequency converter supported power estimation or measured power values in combination with an already existing sensor as input information for an on-line tuning strategy leads to exact results. In this way, the algorithm tunes the real system behavior to the most efficient operation (Figure 1). An advanced Nelder-Mead (NM) algorithm [5] is chosen and modified by a noise signal to improve the convergence behavior to adjust the speed.

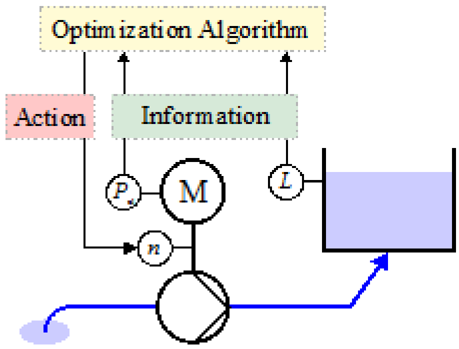

Figure 1. Pump system with a source, pipeline, storage and electric motor including the needed information for the optimization algorithm.

A model of a pump system with a pipeline and storage is realized in Matlab/Simulink, which is presented in this contribution, to develop the algorithm. Furthermore, two kinds of optimization constraints, which are implemented in the system, are displayed. These constraints ensure a maximum filling time and a steady filling process.

2. MODEL OF CENTRIFUGAL PUMP AND FLUID STORAGE SYSTEM

The regarded system (Figure 1) consists of a variable speed driven centrifugal pump, a pipeline and fluid storage, which is filled from below. This filling from below leads to an increasing static head during filling and therefore to a change in the system characteristics.

This system can be divided into three physical subsystems. The first one is the *pumping set*, which determines the delivery head and the shaft power for a certain rotational speed and flow rate. The second part uses the pump head to calculate the dynamic head in the *pipeline* subsystem. The third subsystem, the *storage* subsystem calculates the current storage level utilizing the flow rate, which affects back to the pump system (Figure 2).

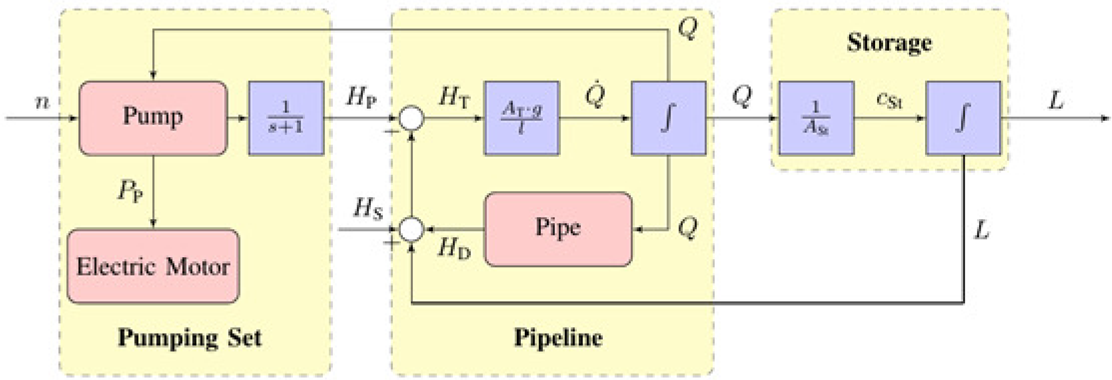

Figure 2. Block diagram of a pump system with pipeline and storage.

2.1. Pumping Set

The characteristic curves of power P_P describe the pump behavior and pump head H_P as functions of the flow rate Q (Figure 3). Employing the affinity laws the rotational speed n and the reference rotational speed n_n are included in the model. Proper results for H_P and P_P, depending on pump series, can only be reached in the closer area of the reference characteristic curve. This effect is caused by varying maximum efficiency peaks at different speeds due to effects like inappropriate incident flow or return flow [6].

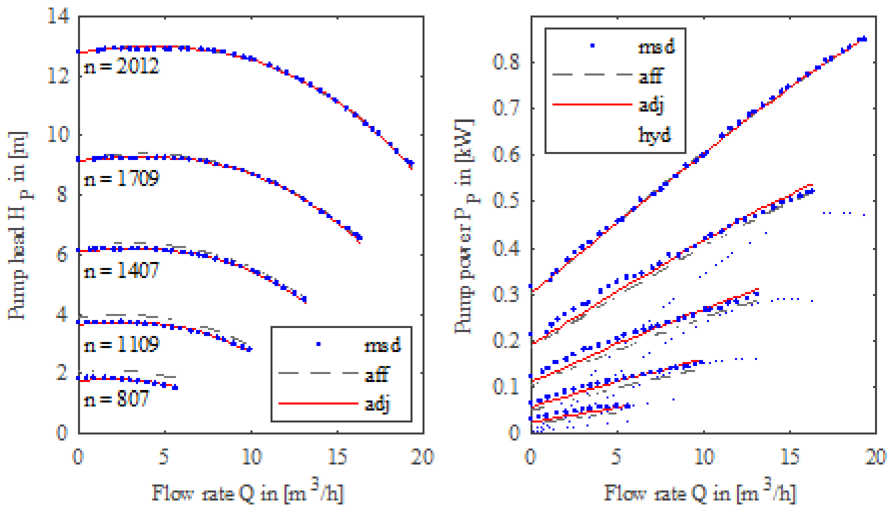

Figure 3. QH- and QP-characteristics of a modeled pump with the measured values (msd), affinity laws (aff), adjusted values (adj) and hydraulic power (hyd).

The reference speed Is $n_n = 2012\,\text{rpm}$.

The modeled pump *KSB Etanorm 050-032-125* characteristics are measured and calculated with the help of polynomial functions of order j with their polynomial coefficients A_i and B_i. Correction parameters $c_{1,2}$ are implemented (Eq. 1) to adapt the head deviations. Considering the differences of P_P the method according to Staufer with the assumption $n_1/n_2 = Re_1/Re_2$ is adduced (Eq. 2) [7] after [8]. Using this adjusted affinity laws better correlations between measured and modeled results are given (cf. Figure 3).

$$H_P = \sum_{i=0}^{j} (A_{i+1} \cdot Q^{j-i} \cdot (\frac{n_n}{n})^{j-i-2}) + c_1 \cdot n + c_2 \tag{1}$$

$$P_P = \sum_{i=0}^{j} (B_{i+1} \cdot Q^{j-i} \cdot (\frac{n_n}{n})^{j-i-3}) \tag{2}$$

2.2. Pipeline and Storage System

The pipeline (PT_1-system) calculates a one-dimensional flow—the static head is set to $H_S = 0$ due to time independence; g describes the gravity, A_T the cross-sectional area of the pipe, l the pipe length and k (Eq. 4) the dynamic pipe resistance. The storage (I-system) consists of its cross-sectional area A_{St} and the filling level L. Both systems combined can be described with the transfer function (Eq. 3) according to [3].

$$\ddot{Q} + \frac{2 \cdot A_T \cdot g \cdot k}{l} \dot{Q} Q + \frac{A_{\mathrm{T}} \cdot g}{l \cdot A_{\mathrm{St}}} = \frac{A_T \cdot g}{l} (\dot{H}_{\mathrm{P}} - \dot{L}),\ Q \le 0 \tag{3}$$

$$k = \frac{1}{2 \cdot A_{\mathrm{T}}^2 \cdot g} \cdot (\lambda \cdot \frac{l\sqrt{\pi}}{2\sqrt{A_{\mathrm{T}}}} + \zeta) \tag{4}$$

Here ζ terms the loss coefficient and λ the friction factor, which is divided into three ranges depending on the Reynolds Number Re (Eq. 5). In the turbulent flow regime, the factor is determined by the approximation after [9], whereby r describes the tube roughness. In the laminar regime, the Hagen-Poiseuille law and in the transition area ($2320 \le \mathrm{Re} \le 3000$) quadratic interpolation are applied.

$$\lambda = \begin{cases} 64 / Re & \text{for } Re < 2320 \\ 1/(-1.8 \ln(\frac{6.9}{Re} + (\frac{0.5\sqrt{\pi} r}{3700\sqrt{A_{\mathrm{T}}}})^{10/9}))^2 & \text{for } Re > 3000 \end{cases} \tag{5}$$

2.3. Model Verification

To verify the static behavior the correlations of the measured values and the simulated values are shown using the impeller diameter D, the dimensionless head Φ (Eq. 6) and power Ξ (Eq. 7) in Figure . For both characteristics, good correlations are reached (slope of the mean relationship ($\rho \approx 1$). At lower speeds ($n \approx 800$ rpm) the modeled and measured power are deviating.

$$\Phi = H_{\mathrm{P}} / (n^2 \cdot D^2) \tag{6}$$

$$\Xi = P_{\mathrm{P}} / (n^3 \cdot D^5) \tag{7}$$

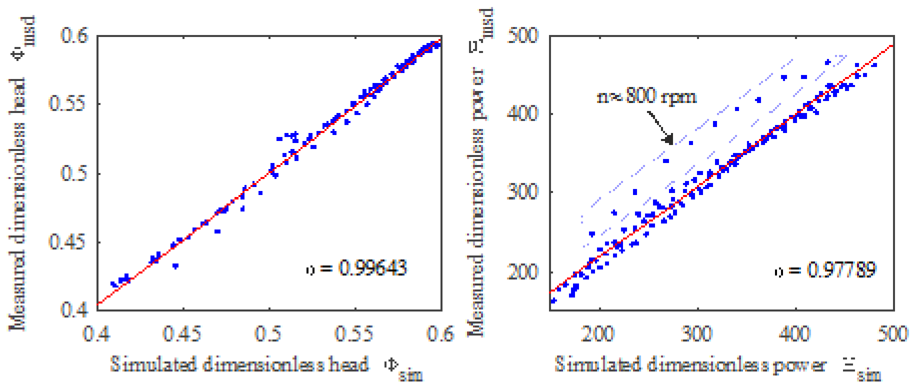

Figure 4. Correlation of simulated and measured dimensionless head and dimensionless power at different speeds (cf. Figure 3).

The model is also tested to its slow transient behavior. Several step responses are recorded for this purpose (Figure 5). The measured speeds are implemented in Simulink. Thus, the simulated speeds are the same. Good results for system gains can be achieved in the range of the reference speed $n_n = 2012$ rpm . At lower speeds, the deviations for head and flow rate are increasing. The overshoot for H_P in the model is higher than the measured one, which causes a higher overshoot for Q . This effect alone does not explain the complete simulated overshoot for Q . For the sake of a robust simulation further model fitting is not done.

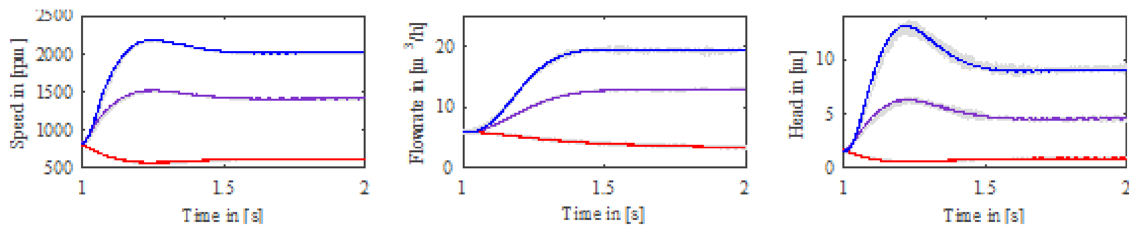

Figure 5. Simulated (grey) and measured step responses for flow rate and pump head for rotational speed set points: $n = 600 \rightarrow 800$; $n = 800 \rightarrow 1400$; $n = 800 \rightarrow 2000$.

3. Optimization with System Integrated Constraints

To satisfy maximum time limits and also to avoid an unsteady filling process rotational speed constraint have to be implemented. The relationship between parameterization of the speed control, which is guided by the current filling level and the maximum time respectively an unsteady filling process ($H_P \leq L$) is not precisely defined. Because of that lack of knowledge, the constraints can't be directly integrated into the OA. They are calculated through the time force control (TFC) and level force control (LFC).

The realization of the tuning program consists of several subroutines and is shown in Figure 6. At the beginning, a function for predicting a filling level L_c has to be adapted. After that, the system is operating using the given starting values $\overrightarrow{a_0}$. The NM can begin when the best result of w_0 is running without TFC. The operation is continuously checked by the subroutines LFC and TFC.

3.1. Optimization

The minimization of the energetic energy demand per filling is realized by adapting parameters a_i , which describe the coherence between speed and filling level and the static head:

$$n_{opt} = a_1 + a_2 \cdot (L + H_S)^{a_3} \quad (8)$$

For finding the values of a_i , the NM algorithm is modified to improve the optimization. Firstly, if the current target value w is smaller than $w < 0.7 \cdot w_{0,min}$, the OA creates new starting values a_0 around the new best point to better examine this area. Secondly, to improve the dynamic behavior of the algorithm, the calculated parameters for $\vec{a}$ are varied with a noise signal s (Eq. 9). NM uses the centroid vector $\overrightarrow{a_c}$ of $n+1$ values for an n-dimensional problem in combination with a chosen action $\vec{x}$. Because of the decreasing influence of the NM-action due to nearing values to the centroid, the impact of the noise is fading away.

$$\vec{a} = \overrightarrow{a_c} + \vec{x} \cdot s \quad \text{with} \quad \vec{a} = \begin{pmatrix} a_1 \\ a_2 \\ a_3 \end{pmatrix} \quad (9)$$

The target value w in this contribution is the used filling energy E, which is calculated by integrating P_P (Eq. 10). In case of using LFC a penalty value E^+ is added to the target value. For using TFC no additional penalty is necessary through an increase of power at higher speeds. The OA is terminated when b in Eq. 11 is smaller than a given termination tolerance (w_j are the n best target values and w_c is the centroid of them).

$$w = E^+ + \int_{t=0}^{t=\max} P_\text{P} \cdot dt \tag{10}$$

$$b = \sqrt{\sum_{j=1}^{n} \frac{(w_j - w_\text{c})^2}{n}} \tag{11}$$

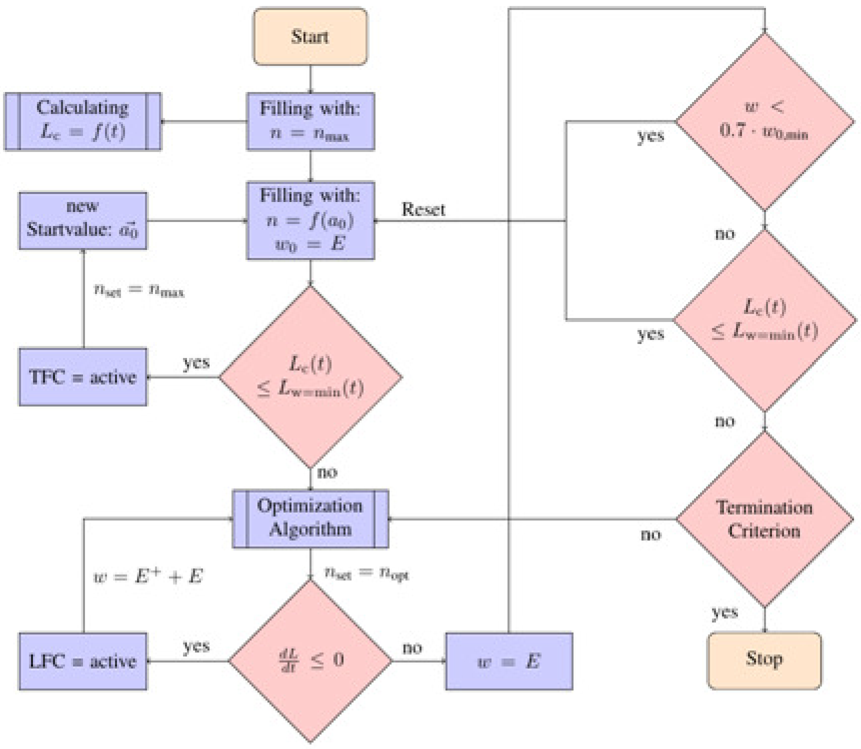

Figure 6. Flow chart for the tuning program.

3.1. Built-In Constraints

The TFC checks to see, which predicted filling level L_c can be achieved during a maximum filling time t_max. Therefore, the pump is operating with maximum speed at the first filling to the given filling level L to determine the shortest possible filling time $t_{\text{n=max}}$. In the next step, the TFC can be applied by checking Eq. 12 at the current filling time t:

$$n_\text{set} = \begin{cases} n_\text{opt} & \text{for } L_\text{c} > L \\ n_\text{max} & \text{for } L_\text{c} \leq L \end{cases} \quad \text{with } L_\text{c} = \frac{\Delta L}{t_{\text{n=max}}} \cdot (t_\text{max} - t) \tag{12}$$

The LFC consists of a discrete ID-controller transfer function. An impulse with amplitude $\sigma = 1$ is given to the controller if $dL/dt \le 0$, which leads to a constant increase of speed. An exemplary behavior of both constraints is shown in Figure 7.

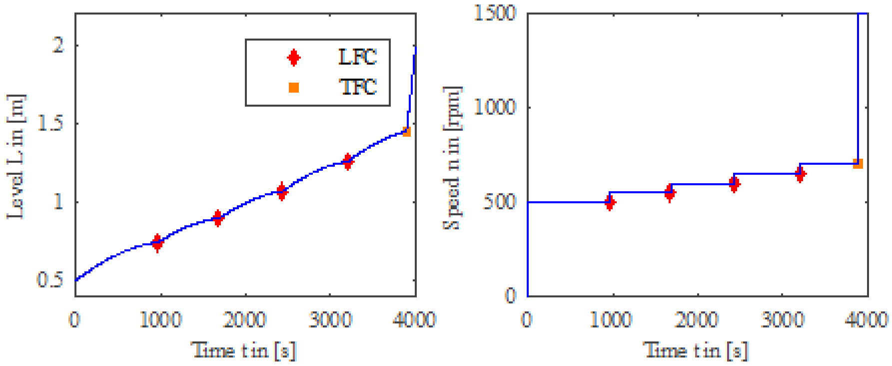

Figure 7. Filling with maximum filling time $t_{max} = 4000\,\text{s}$ using LFC and TFC.

4. BEHAVIOR AND ANALYSIS OF THE OPTIMIZATION ALGORITHM

The tuning algorithm is tested five times each for six maximum filling times. With a maximum permitted filling time of $t_{max} = 5000\,\text{s}$ no time constraint is necessary because of $t_{Energy=min} < t_{max}$. For this case and for $t_{max} = 3500\,\text{s}$ the tuning processes are shown in Figures 8 and 9.

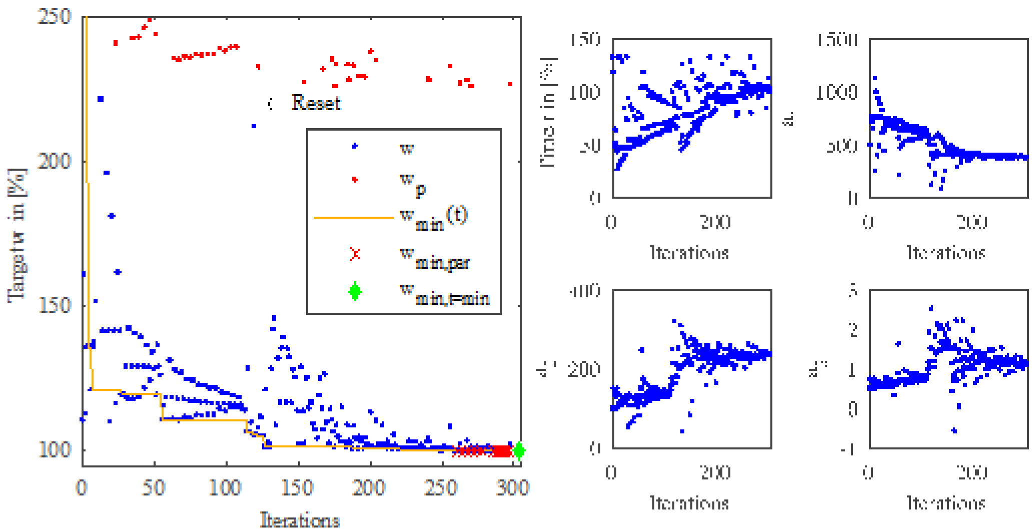

Figure 8. Decrease of the target value w and tuning of a_1, a_2, a_3 during optimization with maximum filling time $t = 3500\,\text{s}$.

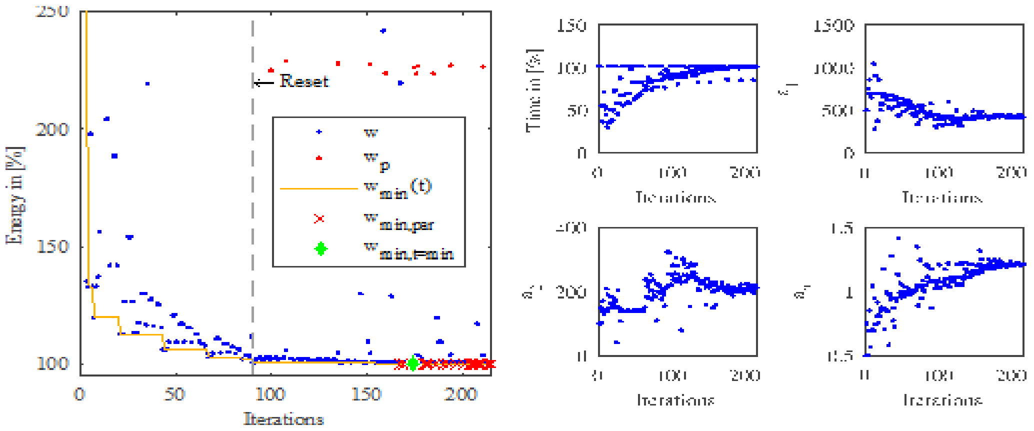

Figure 9. Decrease of the target value w and tuning of a_1, a_2, a_3 during optimization with maximum filling time $t = 5000\,\text{s}$.

It can be seen, that the target values w respectively w_p (with additional penalty E^+) are decreasing to a minimum during the tuning process. The trends of w_{min} show the minimum detected amounts at the current optimization step. Several best points are found before the termination criterion cancels the optimization. This Pareto optimality is shown with $w_{min,par}$, whereby $w_{min,t=min}$ shows minimum filling energy in combination with minimum filling time. The reset points are occurring due to $w = 0.7 \cdot w_{0,min}$.

The final results for all optimizations are shown in Figure 10. The tuned energy E_{opt} is compared to the energy demand E_{bf} optimized by Brute Force and E_q using constant flow rate control. Especially at shorter filling times, the percentage w for continuous flow rate rises sharply. The Brute Force method shows that good results are reached using this presented optimization method.

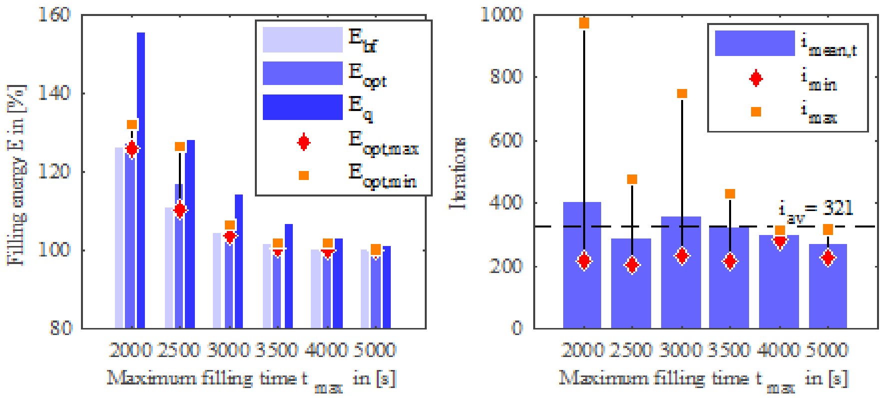

Figure 10. Energy demand referred to its minimum and resulting iterations for five optimizations per fixed maximum time.

The bars for E_{opt} are showing the mean results for five tuning processes, whereby $E_{opt,max}$ and $E_{opt,min}$ are the maximum and minimum found final value. The authors recommend more optimizations per filling time to avoid these local minima. The average number of iterations is given with $i_{av} = 321$. Nevertheless, two times the numbers of iterations $i > 700$ are occurring.

4. CONCLUSION AND OUTLOOK

In this contribution, an energetic optimization for centrifugal pumps to fill storages was presented. The requirement for the task is a maximum permitted filling time, which is handled by the time force control. An additional subroutine, the level force control, ensures a steadily filling process.

Using this method, frequency-based power estimation or installed power measurement in combination with and filling level sensor the plant can be tuned on-line during operation without plant characteristics from data-sheets and calculated pipeline resistance. Compared to fillings with a constant flow rate, high savings are possible, especially at shorter filling times.

The presented method for energetic optimization of filling fluid storages with a maximum permitted filling time will be tested in a pump test rig in future work. Additional problems like measurement noise for the power and filling level signals are expected. This difficulty may be managed by implementing proper filter methods. Another possible parameter to adapt the rotational speed is the current filling time, which reduces installation costs by abandoning the level sensor.

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Authors

Thomas Hieninger (M. Sc.),
2007-2011: Mechanical Engineering (B.Eng.) at OTH Regensburg
2011-2013: Process Engineering (M.Sc.) at Friedrich Alexander University Erlangen-Nürnberg since
2014: Research Assistant at Nuremberg Campus of Technology; active in the field of energy efficient control of pump systems

Florian Goppelt (M. Eng.)
2010-2014: Mechatronics (B.Eng.) at TH Nürnberg Georg Simon Ohm
2014-2015: Electronical and Mechatronic Systems (M.Eng.) at TH Nürnberg Georg Simon Ohm Since
2016: Research Assistant at Nuremberg Campus of Technology; active in the field of mathematical modelling, control and observation of pump systems

Prof.-Dr.-Ing Ronald Schmidt-Vollus
1991-1997: Education in Chemical Engineering at Friedrich Alexander University Erlangen-Nürnberg (FAU)
1998-2004: Control engineering and process automation, commissioning of process control systems
1994-2006: Development associate for process control systems
2006-2013: Head of Development (process control) ProLeiT AG, Herzogenaurach
2011: Ph.D. Degree (Dr.-Ing) at Friedrich Alexander University Erlangen-Nürnberg (FAU)
Since 2013: Professor for control technologies, Nuremberg Campus of Technology, Technische Hochschule Nürnberg Georg Simon Ohm.

AUTHOR INDEX