Universidade de Trás-os-Montes e Alto Douro

Programa de pós-doutoramento

Relatório de Atividades

Desenvolvimento de sistemas ciberfísicos e análise de dados para aplicação em ambientes de produção agrícola

Candidato: **João Paulo Coelho**

Orientador: **Prof. Dr. José Boaventura Ribeiro da Cunha**

Coorientador: **Prof. Dr. José Paulo de Moura Oliveira**

Dara de Início: **setembro de 2018**

Data de Conclusão: **julho de 2019**

Conteúdo

Introdução

Quase duas décadas depois da viragem do milénio, assiste-se a uma nova mudança de referência em todos os processos produtivos. Depois da máquina a vapor e da informação, segue-se a digitalização. Tal como aconteceu com a terceira revolução industrial, a tecnologia que começou inicialmente a ser empregue na indústria, acabou por contagiar outros setores económicos e sociais nomeadamente aqueles que se referem aos setores primários como é o caso da produção agrícola. Assiste-se assim à origem da agricultura de precisão onde a informação e os métodos de análise de dados desempenham um papel fundamental. É nesta conjuntura que o presente trabalho de pós-doutoramento assenta. Em particular, a análise da forma como técnicas que provaram ser vantajosas no domínio industrial podem ser migradas para o setor agrícola. Fala-se, por exemplo, em gestão e manufatura "lean" onde a análise atempada da informação proveniente dos processos é fundamental na redução dos desperdícios, "rework" e qualidade do produto.

A transposição destas técnicas, do domínio industrial para o domínio rural, não é fácil nem direta visto que os processos agrícolas ocorrem em ambientes tipicamente mais hostis e imprevisíveis que os primeiros. Ou seja, muitas das variáveis envolvidas na produção não são diretamente manipuláveis como é o caso da volatilidade das condições ambientais ou o aparecimento e propagação de pragas e doenças. No entanto, acredita-se que as técnicas de inteligência artificial e aprendizagem máquina utilizadas atualmente em manufatura industrial podem ser adaptados à realidade agrícola. Para isso, a aquisição massiva de dados é uma condição fundamental para que este tipo de algoritmos possam criar valor. A questão prende-se acerca do tipo de dados a monitorizar e que tecnologias utilizar nesse processo.

A presente proposta de trabalho de pós-doutoramento está alinhada com esta temática sendo focada para o caso particular da gestão de água em sistemas de produção por fertirrigação. Em particular, o recurso a técnicas de supervisão e controlo multiagente com base na informação fornecida por uma rede de dispositivos ciberfísicos. Um dispositivo ciberfísico é um elemento da cadeia de produção que possui a capacidade de comunicar com outros nós nessa mesma cadeia, fazer recolha e processamento de dados, tomada local de decisões, etc. Para o problema em questão, será da responsabilidade de cada dispositivo ciberfísico determinar, com base nas informações locais fornecida por um conjunto de sensores, o nível de fertirrigação desejável. Neste contexto, as redes de comunicação de dados e os transdutores e dispositivos de sensorização desempenham um papel fundamental isto porque a assertividade das decisões tomadas depende fundamentalmente da quantidade, qualidade e instantaneidade da informação veiculada pelos processos.

Objetivos Propostos

No seguimento da secção anterior, o plano de trabalhos inicialmente traçado era bastante ambicioso e procurava alcançar os seguintes objetivos:

- Desenvolver uma rede de sensores, com nós de baixo custo, capazes de efetuarem a medição local de diversas variáveis ambientais. Entre elas a humidade do substrato;
- Implementar um sistema de análise de dados recorrendo a uma das PaaS atualmente existentes;
- Construir um sistema de controlo distribuído usando agentes executados sobre plataforma "JADE".
- Publicação de um artigo em revista internacional indexada (ISI ou Scopus);
- Publicação de um artigo em conferência internacional indexada (ISI ou Scopus);
- Submissão de uma candidatura, em linha com o trabalho a desenvolver ao longo deste programa, a um projeto europeu de financiamento.

Objetivos Atingidos

De entre os objetivos enumerados na secção anterior, grande parte deles foram concretizados. No entanto, e como será descrito adiante, o facto da candidatura a financiamento não ter aceite, apesar de todo o envolvimento necessário à sua preparação, veio colocar sérios entraves à realização de algumas das atividades. Em particular:

- Foi desenvolvida uma rede de comunicação LoRa constituída por três nós de comunicação. Essa rede de comunicações foi testada em ambiente laboratorial podendo ser escalada para uma maior dimensão quando for conseguida verba para aquisição de todos os *transceivers* e *gateways* necessários;
- A humidade do solo é um parâmetro fundamental. Para isso foi feito um estudo da robustez, precisão e repetibilidade de sensores resistivos e capacitivos comercialmente existentes. Um artigo está atualmente a ser preparado onde os resultados obtidos serão apresentados;
- A implementação do sistema de análise de dados em plataformas remotas foi um dos objetivos não atingidos devido a várias razões entre as quais o facto da rede de sensores não ter sido implantada na instalação hortofrutícola como era objetivo;
- Dado que o sistema multiagentes é uma camada de alto nível que requer que a rede de comunicações esteja concluída, este foi também um dos objetivos que não foi completamente atingido.
- Ainda que não tenha sido publicado nenhum artigo diretamente associado com o tema deste trabalho, foi publicado um artigo em revista internacional que envolve uma técnica de controlo que poderá vir a ser utilizada neste contexto;
- Foi publicado um artigo na conferência EPIA2019 onde se apresentou o conceito proposto neste trabalho;
- Foi submetida uma candidatura ao programa PRIMA 2019 para financiamento dos trabalhos de pós-doutoramento.

Nas secções que se seguem, será descrito de forma mais detalhada, o resultado das atividades científicas resultantes do período que se estende de setembro de 2018 a julho de 2019. É importante salientar que estas atividades se encontram divididas em duas partes: uma em que estas se encontram diretamente ligadas aos trabalhos de pós-doutoramento e outras, ainda que pertinentes para avaliar o percurso científico do candidato no último ano, não estão diretamente ligadas a este grau académico. No entanto, tanto umas como outras, capitalizam e refletem a capacidade científica do candidato pelo que são descritas neste documento.

Atividades Científicas Diretamente Ligadas ao Tema

Preparação e submissão de projeto internacional

Em fevereiro de 2019, e após quase um semestre a redigir documentos técnicos e operacionais assim como reunir com parceiros nacionais e internacionais, foi submetida, para financiamento, uma proposta de projeto de investigação ao programa PRIMA 2019.

PRIMA é acrónimo de “Partnership for Research and Innovation in the Mediterranean Area” e trata-se de uma iniciativa fundado sob os auspícios do quadro de financiamento Horizonte 2020 – o programa da União Europeia para a Investigação e Inovação. A principal missão desta entidade é a de apoiar e promover a integração, o alinhamento e a implementação conjunta de programas de I&D com o propósito de enfrentar os diversos desafios em escassez de água, agricultura e segurança alimentar.

A proposta submetida encontra-se alinhada como tema dos trabalhos de pós-doutoramento e intitulava-se “*An agent-based fertigation approach to sustainable management of water resources in Mediterranean agrosystems*” identificada abreviadamente pelo acrónimo TECinAGRO. Resumidamente, a proposta submetida seguia a descrição apresentada no decorrer do capítulo 2 deste documento.

No anexo A_1 a este documento, apresentam-se os resultados da avaliação da proposta onde se pode verificar as excelentes críticas feitas pelos membros do júri. No entanto, e apesar de ter sido positivamente avaliada, esta proposta não obteve financiamento como se pode constatar pela cópia de email anexada em A_2. A razão apontada para este resultado prendeu-se com o elevado número de submissões o que implicou a que a taxa de aceitação se situasse em torno dos 15%.

O facto desta proposta não ter obtido financiamento veio condicionar a forma como os trabalhos de pós-doutoramento foram realizados nos meses que se seguiram. É de salientar que no quadro atual do financiamento das instituições de ensino superior, as verbas para I&D são escassas ou mesmo inexistentes pelo que a inexistência de um programa de financiamento externo de suporte coloca em causa o andamento dos trabalhos. No entanto, e apesar do resultado inesperado do programa PRIMA, os trabalhos prosseguiram ainda que a um ritmo diferente do que teria sido possível com verbas atribuídas. Com efeito, e decorrente dos trabalhos levados a cabo no contexto deste programa de pós-doutoramento, foram escritos dois artigos científicos conforme se descreve nas duas próximas secções.

Publicação de artigo em conferência internacional

Na sequência das atividades realizadas no âmbito deste pós-doutoramento, foi escrito o artigo intitulado "*Cyberphysical Network for Crop Monitoring and Fertigation Control*" tendo sido aceite para apresentação no decorrer da conferência EPIA 2019 que teve lugar no início de setembro de 2019. Este artigo encontra-se publicado sob o DOI 10.1007/978-3-030-30241-2_18 no livro *Progress in Artificial Intelligence*, páginas 200 a 211, publicado pela *Springer International Publishing*. Uma cópia deste artigo encontra-se no Anexo B deste relatório.

Atividades Científicas Realizadas à Margem do Tema

Ainda que não exista uma ligação direta entre as atividades que serão enumeradas durante este capítulo e o tema inicial da atividade de pós-doutoramento, considera-se fundamental apresenta-las dado que permitem uma melhor caraterização do percurso científico no decurso deste último ano.

Publicação de livro

No decurso do ano de 2018 foram efetuados contatos com a editora CRC no sentido de se avaliar o interesse dessa editora num manuscrito que foi desenvolvido ao longo dos últimos anos. Como é do domínio público, a CRC é uma empresa de publicação de livros técnicos sediada em Boca Raton, Florida, nos Estados Unidos da América. Trata-se de uma editora extremamente conceituada no meio académico contando com mais de quatro décadas de existência. O trabalho apresentado foi considerado e aceite para publicação estando, desde agosto de 2019, disponível para compra em:

https://lnkd.in/dyUMhF9

Ainda que todos os detalhes possam ser consultados a partir do link referido, no Anexo C a este documento, por conveniência, apresenta-se o índice do livro.

Publicação de artigo científico em revista internacional

No dia 15 de maio de 2019 foi publicado na revista científica *Actuators*, o artigo intitulado "Semi-Active Vibration Control of a Non-Collocated Civil Structure Using Evolutionary-Based BELBIC". Sendo uma revista *open access*, uma cópia do artigo pode ser descarregada a partir do endereço:

https://www.mdpi.com/2076-0825/8/2/43/htm

Participação em eventos científicos

No dia 9 de maio de 2019, e no contexto da *Semana do Empreendedorismo Tecnológico* promovida por um consórcio constituído, entre outros pelo Instituto Politécnico de Bragança e pelo Núcleo Empresarial de Bragança, participou na qualidade de palestrante na *Mesa Redonda* subordinada ao tema **Machine Learning**. O certificado de participação neste evento encontra-se apresentado no Anexo D.

Fez parte da organização local do evento xTIE promovido pela Universidade do Minho. O projeto xTIE visava sensibilizar as PME, nomeadamente na região Norte, para aspetos relacionados com as TICe (tecnologias da informação, comunicação e eletrónica), e o seu papel como forma de alavancar a competitividade e o dinamismo dos vários setores económicos e sociais. O evento teve lugar nas instalações do Brigantia EcoPark nos dias 28 de novembro de 2018 e 3 de abril de 2019.

Desde Julho de 2018 que faz parte do comité organizador da conferência CONTROLO`2020 tendo sido responsável, entre outras tarefas, pela execução e manutenção da página da internet em https://controlo2020.ipb.pt

Participação como formando

No dia 8 de abril de 2019 concluiu com aproveitamento final de 94% o curso de *Simulação e Controlo de Drones* promovido pelo Instituto Superior Técnico. O curso teve a duração de 4 semanas com uma taxa de esforço estimado de 5 horas por semana. Detalhes deste curso, assim como uma cópia do certificado de participação, podem ser encontrados no Anexo E a este documento.

No dia 29 de maio de 2019 participou no seminário "O futuro do ensino superior de qualidade é blended e flipped: experiências com o modelo de sala de aula invertida na Universidade de Alcalá – Madrid e a extensão do modelo flipped às universidades espanholas". Uma cópia do certificado apresenta-se no Anexo F.

Conclusão

Entre setembro de 2018 e julho de 2019 o candidato teve o privilégio de ser aceite como aluno de pós-doutoramento na Universidade de Trás-os-Montes e Alto Douro: um bastião científico e tecnológico na região norte de Portugal. Teve ainda a honra de ter o Prof. José Boaventura-Cunha e o Prof. Paulo de Moura Oliveira como orientadores dos trabalhos desenvolvidos neste contexto. O alcance dos objetivos acima descritos muito se ficou a dever à sua competência científica. Infelizmente, o facto deste trabalho não ter conseguido financiamento, e visto que um ano não é muito tempo para se perseguirem objetivos tão ambiciosos como os que foram inicialmente traçados, fez com que algumas das metas não tenham sido completamente atingidas. No entanto, acreditando que um grau de pós-doutoramento deve refletir mais do que um conjunto focado de eventos científicos, ao longo deste documento foram também descritas todas as atividades científicas em que o candidato esteve envolvido durante o ano letivo 2018/2019. Considera-se que desta forma, a maturidade científica que conduz à atribuição do grau de pós-doutoramento pode ser mais facilmente aferida.

ANEXOS

Anexo A1

Projet / Proposal	
Acronyme / Acronym	TECinAGRO
Titre / Title	An agent-based fertigation approach to sustainable management of water resources in Mediterranean agrosystems

Coordinateur du projet			
Prénom / First Name	João	**Nom / Last Name**	Coelho
Téléphone / Phone		**Email**	jpcoelho@ipb.pt
Organisme / Institution	CeDRI		

RETOUR AU COORDINATEUR / COMMITTEE REPORT

1. Excellence / Excellence

Clarity and pertinence of the objectives; Soundness of the concept, and credibility of the proposed methodology; Fit with the scope and objectives of the PRIMA programme and the call topic description Extent that the proposed work is beyond the state of the art, and demonstrates innovation potential (e.g. ground-breaking objectives, novel concepts and approaches, new products, services or business and organizational models) Appropriate consideration of interdisciplinary approaches and, where relevant, use of stakeholder knowledge and gender dimension in research and innovation content

Clarity and relevance of the objectives: The TECinAGRO project proposal aims to develop and implement an intelligent monitoring and control system, which can be used to upgrade an existing installed fertigation production system, aiming at a rational water consumption and fertilization management. In particular, the current proposal focuses on the implementation of an Internet-of-Things (IoT) based technological solution applied to precision irrigation for fertigation-based crop growing systems. The general objective is clear and well defined - the implementation of the fertigation concept as an advanced crop growing technique that provides precise injection of the nutrient solution into irrigation water according to plant requirements, climate and substrate, soil conditions. Fertigation ensures reduction of fertilizers, phytopharmaceuticals and water application, while improving efficiency of water use and nutrients, which can improve vegetable production and reducing the environmental consequences of agriculture and its running cost. These aspects are well considered.

Fitting with the scope and objectives of the PRIMA programme and the call topic description: The proposed research fits well to the PRIMA thematic area number 2 Farming Systems 2019, Topic 1.2.1: Conserving water and soil in Mediterranean dry-farming, smallholder agriculture.

Soundness of the concept and credibility of the proposed approach/methodology: The concept of the project is very straightforward and clear. A wide range of project activities are well explained and justified. What makes the proposal very convincing is careful justification and quantification. Individual activities are very well described and explained. The WP structure (eight WPs) is described in a rather concise way, but the activities are more than sufficiently explained in the Methodology and Concept section. Very long and detailed description of activities and goals of four pilot case studies make the proposal outstanding in this aspect. A crop irrigation schedule is usually defined by the farmer based on intuition or, automatically, using indirect information such as temperature, solar radiation or even the water level present in the gutter's runoff channels in the case of greenhouses. This automation model translates into a suboptimal irrigation scheme since it does not consider the crop vegetative development stage, the climate idiosyncrasies at each growing stand, and the water content and actual nutrient concentration level present at the crop substrate/soil. To attain this objective, each growth stand in both greenhouse and open field pilot cases will be upgraded to a cyberphysical device. Several hundred cyberphysical devices, in a production system, will interact based on an agent-based ecosystem. With this technological solution, optimal nutrition control is achieved taking into consideration both the current and predicted climate conditions and the crop vegetative states. The full solution relies mainly on open-source technologies which will stimulate its dissemination among other growers. Following an IoT technological paradigm, the system can be easily scaled. The use of open source technologies and platform will facilitate its deployment to other growers that share the same production scheme. The concept is also based on drainage water reuse and mixing with collected greenhouse roof rain water. It will therefore promote the adoption of conservation agriculture by the farmers. The project is expected to interview farmers, stakeholders, policy makers and associations to establish socioeconomic constraints and agroecological characterizations in Mediterranean countries which is a strength. The proposed architecture will be tested and evaluated under different scenarios within four pilot cases, representing the predominant conditions of Mediterranean basin either in open field and greenhouses which is good. However, it is not understood why the fertigation will "occur only on growing stands" although it is successfully applied in the greenhouses and open field. Also, it is not clear why the concept shifted from the intensification of vegetable production through a sophisticated set of sensors for fertigation for precise fertilizer and water delivery to the conservation agriculture based on the reuse of plant residues from the greenhouse to be applied in the open field to compensate for the organic carbon loss.

The project suffers from some shortcomings: (i) There are some inconsistencies between the objectives of the proposal appearing in p. 2 and and those listed in page 9 (why present the objectives twice?) which lead to unnecessary confusion as to the goals the project is aiming to achieve. (ii) The project proposes to adopt industrial manufacturing processes to fertigation-based agricultural production. This seems like a novel idea but how this concept will be achieved in the project is not clear. (iii) It is proposed to use many types of technologies in the project aimed at improving fertigation, among which are sensors located in the growing media. No reference is made as to the number of sensors needed per unit area, their location with respect to the fertigation line, depth of installation, etc. Moreover, the role of spatial variability in the growing media which can significantly affect all the decisions regarding the location and density of the sensors to be used is not considered. (iv) The project leans heavily towards data acquisition and not sufficient efforts seem to be devoted to relating the acquired data to crop status and needs and subsequently into agronomic management activities.

Extent that the proposed work is beyond the state of the art, and demonstrates innovation potential: The innovation potential of the project is high. It lies in the implementation of an Internet-of-Things (IoT) based technological solution applied to precision irrigation for fertigation-based crop growing systems. The setup of cyberphysical systems (CPS), scattered along the production chain are key conditions to agent-based control systems. CPS constitute the edges of the manufacturing network and are responsible for several tasks such as data acquisition, telemetry and local processing. In addition, the rhizosphere approach is important and can provide valuable strategies, additional know-how and knowledge that is relevant for the CA introduction, sustainable use of natural resources (e.g., water, soil) and especially to assure adequate yields and competitiveness of the small-scale agriculture. This aspect is strong.

Interdisciplinary approaches and the use of stakeholder knowledge: the project scores highly in terms of Interdisciplinarity. The proposal promises to integrate various stakeholders, mainly farmers. For instance, farmers and stakeholders will participate in identifying the main barriers that limit the adoption of conservation agriculture. This approach will help to overcome the dissemination of knowledge and introduction of new technologies.

2. Impact / Impact

The extent to which the outputs of the project would contribute to one or several of the expected impacts mentioned in the work plan under the relevant topic.

The extent to which the outputs of the project would contribute to one or several of the expected impacts mentioned in the work plan: The proposal does not list impacts explicitly, yet the main impact can be inferred from the description of objectives, activities and results. The elaboration of this economically feasible system is expected to overcome weather conditions and reduce water use to a degree not to impose hydric stress to the crops. The project outputs are expected to integrate IoT based devices in order to control the irrigation cycles in fertigation-based greenhouse and open field agricultural production schemes. If the latter is achieved it will reduce the water consumption and nutrients supply and optimize the fertigation cycles according to the actual vegetative state and crop hydric stress. Another possible important output: the cyberphysical devices and decentralized control system would help the grower to increase their control over the irrigation/fertigation within their production crop resorting to IoT technology and thereby achieve more sustainable, efficient and localized use of the resources, with the same or higher yield of better quality and lower environmental impact. The proposal includes a novel open framework (hardware and methods) to support growers in better decisions and promote the adoption of innovations by farmers. The project provides key performance indicators about water, energy, chemical and cost saving. It is expected that the data aquisition component in the proposed project will be carried out successfully. Yet, the prospects for successful implementation of the second part (relating the acquired data to crop status and thus to the development of a robust decision support system) seem to be much slimmer. Hence, the above mentioned possible impacts may not materialize, at least not in full. The dissemination is based on active participation of stakeholders. The communication and dissemination activities to be undertaken during the project, will include the exchange of experiences, good practices and requirements among the partners and stakeholders. The added value would increase the quality of the proposal if dissemination is better described.

Anexo A2

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De:	fabrice.dentressangle@prima-med.org
Enviado:	17 de maio de 2019 14:58
Para:	jpcoelho@ipb.pt
Cc:	fabrice.dentressangle@prima-med.org
Assunto:	PRIMA RESULTS section 1 Farming Systems
Anexos:	Rapport d'évaluation du comité.pdf

Dear Dr. João Coelho,

PRIMA thanks your participation to the **PRIMA SECTION 1 RIA Conserving water and soil in Mediterranean dry-farming, smallholder agriculture**. Your proposal entitled ***TECinAGRO*** has been positively evaluated by the scientific evaluation panel, however due to the very high level of competition we regret to inform you that it has not been retained to participate to the second stage of evaluation.

Out of the 60 projects evaluated, 9 projects have been invited to submit a full proposal. The proposals have been evaluated according to the criteria described in the guidelines for applicants (http://prima-med.org/wp-content/uploads/2018/12/PRIMA-2019-Guidelines-for-Applicants-Section-1-RIAIA.pdf). The final decision is based on the results of this evaluation carried out by the scientific evaluation panel and is reflected in the Evaluation Summary Report attached.

As coordinator, **you have the responsibility to inform each consortium partner** about this message and to forward to your partners the ESR attached.

We are thankful for the interest you showed for this programme and we hope that you will have the opportunity to participate in future calls. PRIMA will launch new calls for proposals in 2020 and the corresponding information will be published on the PRIMA website http://prima-med.org/

Please do not reply to this e mail, to contact us send your message to the Project Officer in charge of the thematic area you were involved in.

Best regards

Fabrice Dentressangle

The PRIMA PROJECT OFFICERS

Anexo B

Cyberphysical Network for Crop Monitoring and Fertigation Control

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Abstract. The most current forecasts point to a decrease in the amount of potable water available. This increase in water scarcity is a problem with which sustainable agricultural production is facing. This has led to an increasing search for technical solutions in order to improve the efficiency of irrigation systems. In this context, this work describes the architecture of an agent-based network and the cyberphysical elements which will be deployed in a strawberry fertigation production plant. The operation of this architecture relies on local information provided by LoRA based wireless sensor network that is described in this paper. Using the information provided by the array of measurement nodes, cross-referenced with local meteorological data, grower experience and the actual crop vegetative state, it will be possible to better define the amount of required irrigation solution and then to optimise the water usage.

Keywords: Cyberphysical system · Sensor network · LoRA WAN · Precision agriculture · Fertigation control

1 Introduction

The availability of water resources is a fundamental aspect to stabilise the human activities and to maintain the equilibrium of the ecosystems. Besides the need for drinkable water, societies depend on reliable supplies of water for distinct activities such as agriculture and industry. However, it is anticipated that in the near future the amount of available water *per capita* will decrease. There is not a single, but several reasons that converge to this reduction tendency. The two most cited ones are the climate changes felt all over the globe [6] and the increasing population growth, specially in Africa and Asia [18]. A third reason,

P. Moura Oliveira et al. (Eds.): EPIA 2019, LNAI 11804, pp. 200–211, 2019.
https://doi.org/10.1007/978-3-030-30241-2_18

is the contamination of groundwater due to human activities such as sewers, landfills and over application of fertilisers in agriculture [3,19].

Agriculture is the basis of the modern societal structure and supports all the other sectors such as industry and services. As can be presumed, providing food for more than seven billion people world wide imposes a severe load on natural resources in general and in water in particular. Several strategies are currently being developed and applied in order to mitigate this phenomena. For example, the integration of rainwater harvesting systems, the use of fertigation plant growing systems, where both water and nutrients can be tightly controlled, and the integration of state-of-the-art information technologies in the production loop.

Fertigation is an advanced crop growing technique that provides precise injection of fertilisers and irrigation according to plant requirements, environmental conditions and substrate type. The use of fertigation systems has been increasingly popular as an alternative to more classical cultivation techniques. Worldwide, and at the present, more than 11 million hectares of area are associated to fertigation based production schemes. In the context of the Iberian peninsula, fertigation based crop growing systems are being increasingly used for intensive agriculture production [1,5]. Fertigation can be used both outdoor and indoor, with soil as the plant's support or using different substrates such as a mix made of coconut fibres. In this kind of process, soluble type nutrients, such as calcium nitrate and potassium nitrate, phosphoric acid are stored in tanks and injected into water. These solutions are then conduced down to the plant roots area through driplines. Figure 1 illustrates the overall architecture of a fertigation based system. Water is pumped from a reservoir down to the crop production lines. Along this process, venturi injectors apply a predefined amount of each type of nutrient which are stored in different tanks. Besides the nutrients, an additional tank containing an acid solution is also included in order to control the pH of the nutritive solution.

Instrumentation and measurement play a central role in fertigation systems. Besides pH, other variables such as electrical conductivity (EC) and nitrate levels are monitored for the quality of the nutritive solution. Moreover, plant tissue measurements, soil testing, and water analyses are fundamental to provide information about the current production state and to gather information regarding the overall health and productivity of the crop. Agriculture processes can be viewed as very complex time-varying systems since the plants absorb nutrients at different rates along their vegetative states. Failing to keep track on the above referred variables might significantly affect the yield and reduce the economic profit.

Commonly, the irrigation schedule is empirically defined from the farmer's experience or, in a semiautomatic way, based on indirect and imprecise information such as temperature, solar radiation or the water level present in the drainage channels. This form of control, however functional, does not take into consideration the real need for the vegetative development of the plant, the effective level of concentration of the fertigation solution and the difference of the

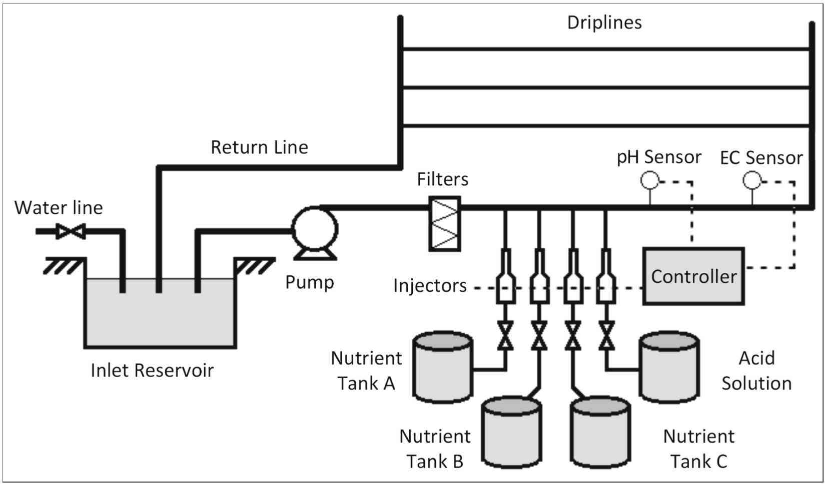

Fig. 1. Overall architecture of a fertigation based system.

environmental conditions, which can vary within the production area, and may cause saturation of nutritive compound or the opposite.

In this work, those problems are addressed by proposing a decentralised, agent-based control system for fertigation crop production. In particular, this strategy will be developed and field tested in a strawberry production plant. The devised control model strongly depends on local information gathered by an array of sensors scattered along the production area. The next section will provide an overview of the current scientific literature that documents the use of sensor networks in agriculture applications. Details regarding the proposed architecture and the experimental setup will be provided in Sect. 3.

2 Sensor Networks in Agriculture

The integration of electronic instrumentation and information technologies, within agricultural production loops, is not a recent subject but has been gaining momentum. Particularly, in the sensors network field, several papers have appeared in the literature during the last ten years.

For example, [21] has presented a method based on wireless sensor networks for potato farming that monitors and decode individual crops and requirements. Therefore, the farmers can potentially identify the various fertilisers, irrigation and other requirements. The authors propose an irrigation management model to estimate agricultural parameters using mathematical calculations and intelligent humidity sensors. In [15], the authors have proposed a smart wireless sensor network to collect data and make it available to end users. [20] present an IoT based systems which aims to provide smart farming systems to end users. Advantages of their approach regarding previous smart farms strategies were enumerated. In [4], they have proposed a method to promote smart agriculture by using automation and IoT technologies. In their paper, the authors have used a ZigBee network, cameras and actuators to implement real-time smart irrigation. More recently, [7] has put forward a sensor network targeting the measurement of soil moisture, air humidity and temperature. The focus of the aimed to support small producers where the owner of the property could access the information in real-time. In [10], a crop monitoring system has been developed aiming to regulate the water and fertiliser in a citrus fertigation production process. In their work, a ZigBee network was used to handle wireless communication. Finally, [16] has developed a wireless sensor network composed of several types of sensors where the acquired information was sent to a web page.

From this literature review, it is evident the use of ZigBee as the wireless communication technology that supports the sensor network information exchange. ZigBee is a technology based on the IEEE 802.15.4 international standard aiming short distances communication with a maximum throughput of 250 kbps. ZigBee has excellent features if a low bit rate local area network is to be implemented. However, it is not the only, or even the most suitable solution, if used within an IoT framework. Specially if large number of nodes are packed in a short area. In some applications, Bluetooth low energy (BLE), ANT, Z-Wave, NB-IoT, SigFox or LoRA can be better alternatives [2,11,12,17].

In this work, a LoRA based wide area network (WAN) is the solutions considered due to the following reasons: first the transceiver price, then the required bandwidth, the network configuration, the transmission range and its power consumption. The price is a fundamental criterion so that the solution can be attractive to the end user. It is important to underline that a large number of measurement nodes would need to be deployed as part of the supervising and control strategy described in this paper. A lower cost will allow a faster capital amortisation and will make it a more appealing solution. The remain reasons are of technical nature: the amount of data to be transmitted by each measurement node will not exceed a dozen of kB per day. The nodes will connect to gateways in a star topology and, in order to make the solution "plug & forget", power consumption is a fundamental issue and will be discussed in the following section.

3 Problem Statement

During this section, the problem addressed within this work will be detailed. First, it will be described the place and conditions where the experimental solution will be deployed. Then, in Subsect. 3.2, the measurement nodes will be described and how they communicate the data to a platform as a service (PaaS). In Subsect. 3.3, the overall agent-based control architecture will be presented. This approach will consider each crop growing stand as a cyberphysical system whose behaviour is monitored by an agent oriented platform.

3.1 Experimental Setup

The monitoring and control strategy described ahead, will be deployed and tested at the Hortiparsil installations. Hortiparsil is a Portuguese SME that produces strawberries using fertigation growing methods. Figure 2 shows a partial view of the growing stands layout.

Fig. 2. Growing stands at the Hortiparsil production greenhouse.

The Hortiparsil production scheme takes place indoor and is composed of several hundreds of growing platforms such as the ones depicted in Fig. 3. Each production row, with a length of around 40 m, is suspended from the greenhouse ceiling by steel cables and made from an iron based trellis, a plastic substrate support and the dripline.

The roots of each strawberry plant are buried in a support substrate made of coconut fibre. The dripline carries the fertigation solution and dispose it, drop by drop, near the plant roots. The irrigation solution not absorbed by the plant or the substrate is recovered at the end of the line and conduced, through hoses, back to the fertigation station inlet reservoir.

As referred during the introduction, the crop schedule irrigation plan is commonly established by the grower based on experience and intuition regarding the current crop nutritive needs. This irrigation scheme usually leads to a suboptimal use of water and nutrients. For this reason, this work proposes the use of an agent-based control framework where the production area will be divided into sectors and each sector, composed of a set of growing stands, will be upgraded to become a cyberphysical element. Sensor nodes will be placed along each section and will communicate data to a centralised data management and analytics platform. Details regarding this sensors network will be addressed in the next section.

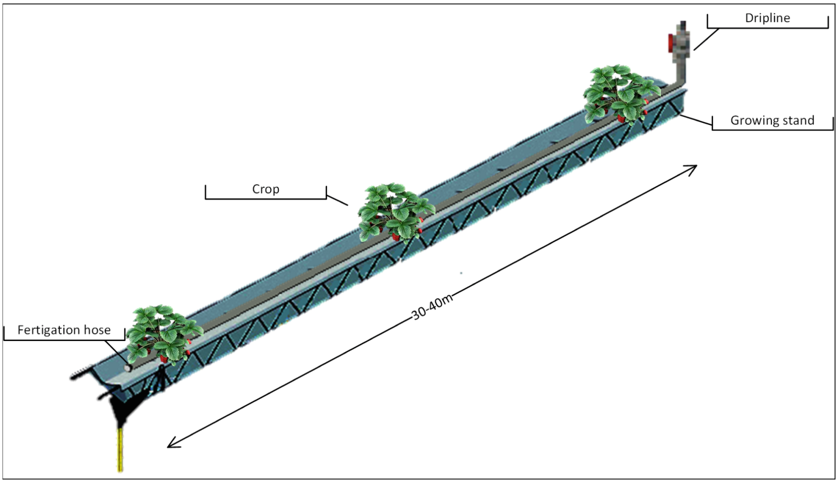

Fig. 3. Schematic diagram of the strawberries growing stands.

3.2 The Sensor Network

Each cyberphysical element will be composed by a set of neighbour growing platforms that share common environmental conditions. A set of measurement nodes (motes) will be distributed along the growing stands gathering information on substrate moisture, air temperature, solar radiation, pH, electrical conductivity, nitrites and nitrates. Artificial vision is also being considered in order to estimate the vegetative state of the crop. But at this point, the sensor network only involves data from environmental and substrate conditions.

The information sent by the motes will be filtered and organised by a software agent that will sent it trough TCP/IP to the PaaS. The communication between the agent and the motes is carried out through a Gateway connected to the motes by using a wireless point-to-multipoint LoRA based network architecture. Figure 4 presents an illustrative diagram of the structure of a generic cyberphysical element.

It is important to highlight that, the time constants involved in the irrigation process are high (generally from ten to sixty minutes depending on the weather conditions). For this reason, the amount of information sent by the transmitter resumes to less than 30 kB during a day time window. Hence, bandwidth is not a variable of concern. However, power consumption, range and number of nodes will steer the selection of the wireless data transmission technology.

With a bandwidth of 125 kHz, LoRA is the wireless digital data communication selected to the current sensors network. This technology supports several data rate modes that can range from 250 bps up to 5470 bps. This very low data rate is balanced by a transmission range that can reach 10 km. It is important to notice that to achieve such high distances it is very important to have a surrounding environment free of physical obstacles and with a high gain antenna.

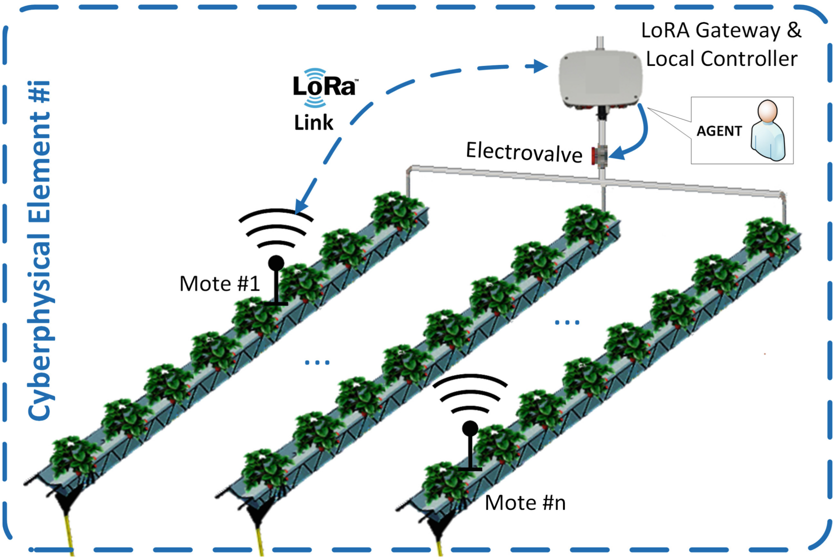

Fig. 4. Schematic diagram of a cyberphysical fertigation element.

From our experiments, 500 m is easily achieved with an isotropic antenna and through building type obstacles. Within the greenhouse, no such distances are required to be covered. However, the crop leafs will contribute to reduce the budget link between the motes and the gateway.

Even if other methods are being tested, at the moment the network operates with a master-slave topology where the measurement nodes are the slaves and the gateway behaves as the master. With a periodicity that could be define between 10 and 30 min, the master sends a request of information to the slaves and then enters into reception mode. The slaves, receiving this request, send the package containing the sensors information. It is worth to notice that all cyberphysical elements are autonomous in the sense that there is no synchronicity between gateways. However, due to high correlation between cyberphysical elements, the PaaS analytics will take this asynchronous incoming information to make a global decision regarding the irrigation schedule.

The number of motes in a sector will depend on the number of available growing stands. Some motes will be responsible to measure air temperature, substrate moisture and electrical conductivity and others will measure nitrites, nitrates and pH. The general architecture of each mote is represented in Fig. 5.

There are many challenges to be solved in the above architecture such as the choice of the sensors, the microcontroller and the power supply technology. Due to the large number of motes that will be installed in a typical cyberphysical element, one of the main concerns is the price. This condition is followed closely by the measurement node power consumption.

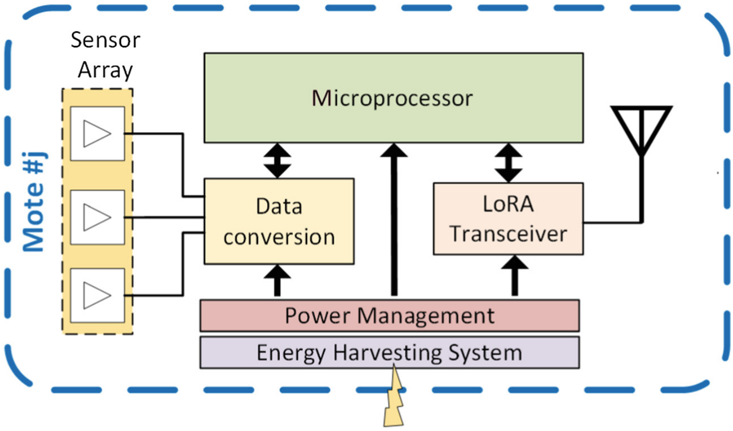

Fig. 5. Sensor nodes (motes) block diagram.

Regarding the sensors, at the present, the prototype is measuring the air temperature using a STLM20 analog temperature sensor. This device ranges from −40 °C to 85 °C with a quiescent power consumption of 15 µW and a shut-down power consumption lower than 70 nW. The substrate moisture is being acquired through an off-the-shelf capacitive type sensor. However, actually different types of sensors are being tested in order to find the one with lower power requirement.

The computation power of the mote is reduced to a simple low power 8 bit microcontroller. In this case, an ATMega328PB, running at 1 MHz with a supply voltage of 3.3 V. This device has a typical power consumption of around 1.5 mW dropping to 0.4 mW when in sleep mode.

The SX1272 LoRA modem is the element with higher power requirements. When in transmission mode, the consumption peaks to 300 mW lowering down to 60 mW when in receiving mode. In sleep mode, those values drop to a power near 0.25 mW. When it operates in the lowest transmission rate mode, the peak power required is only for a time window lower than 10 ms. For this reason, a power consumption average of around 1 mW must be supplied to the mote within a one day operation. That is, a total of 90 J of energy must be provided. A regular LiPo battery is able to pack 9000 J of energy which can lead to a 100 days of full operation until the battery is fully depleted. This solution is unacceptable and is not inline with the concept of “plug & forget” associated to IoT devices. For this reason, energy harvesting solutions are being considered to replace batteries. Nowadays, energy harvesting is considerably simple due to the fact that state-of-the-art DC-DC converters are able to accept input voltages as low as 20 mV and stepping it up to 3.3 V or even higher. For example, the LTC3108, from Analog Devices, is an integrated circuit designed to harvest the energy of thermometric sources. From the same company, the LTC3588 can be used for high impedance sources such as piezoelectric generators. Since the device will operate in a greenhouse, harvesting energy from the Sun is the obvious candidate for powering the device. In this context, we are currently evaluating the use of micro solar panels, from IXYX. In particular, the KXOB22-04X3L module with a total area of $40\,\text{mm}^2$ and, according to the manufacturer, an efficiency 20% higher than amorphous or polycristaline cells. This module is able to deliver a maximum power of 20 mW and an open circuit voltage near 2 V.

For the current mote, an integrates power supply solution is considered where energy will be harvested from the three above referred sources: the thermal difference between the substrate and the air will provide for a Seeback effect energy harvesters, the fertigation solution flow for a piezoelectric generator and the Sun for the micro solar panel. Energy storage will be handled by a capacitor instead of a battery. The main reason is due to the limited life expectancy of the battery when compared to capacitors. Even if batteries can pack a much higher energy value than capacitors, the life expectancy of a capacitor is much greater (theoretically infinite but, in practice, a difference of at least one figure is expected). Since the energy of a capacitor is given by:

$$E = \frac{1}{2}CV^2 \tag{1}$$

where C is its capacitance and V the voltage across its terminals, if the capacitor must be able to store the energy equivalent to two days of operation, $E =$ 200 J which, for a 3.3 V output voltage, leads to a capacitor with a capacitance greater or equal to 37 F. For this capacitance value, a ultracapacitor must be considered. Indeed, the SAMXON 2.7 V, 60 F Ultracapacitor will be elected for the prototype. According to the above equation, it can store a total energy of 218 J which is aligned with the initial requirement.

The mote is only a small piece of the total integrated irrigation control system. The following section addresses the overall architecture where an agent-based decentralised model will be explained.

3.3 The Overall Agent-Based Architecture

The current work aims to develop an integrated solution to control the fertigation of a strawberry production process. As described in Subsect. 3.1, the crop is planted in suspended growing stands and the nutrition solution is carried to the plants through driplines. The current approach considers that this production scheme can be compared to a conventional industrial manufacturing line: the incoming raw material enters (in this case the fertigation broth, the solar radiation and remain environmental conditions) and the final product exits (the strawberries). Some of those variables can be controlled, for example the amount of each nutrient in the fertigation fluid but others are uncontrollable, such as the solar radiation, and must be viewed as disturbances. In this context, the fertigation based production line is even more complex than the common production lines found in typical industries due to the high influence that the uncontrollable disturbances have in the final production outcome. For this reason, it makes sense to migrate some of the Industry 4.0 paradigms into agriculture. In particular, the ones that lead to an increase in robustness, adaptability and waste reduction. Among other approaches, the use of decentralised control methods based on agents has proven to be an efficient solution in the management of complex industrial environments [8,9,13,14]. In agent-based systems, each agent can exchange information with the remain existing agents. Different types of agents are involved in the process: some of them have network management functions while others supervise the cyberphysical entities. In the current proposal, the cyberphysical elements are a collection of neighbour growing stands that share similar environmental conditions. For each cyberphysical element, the information of the current environmental and production conditions are delivered through an array of sensor nodes scattered along the growing stands of the sector. Details on those measurement devices have been provided in subsection 3.2. The overall agent-based fertigation control architecture is represented in Fig. 6.

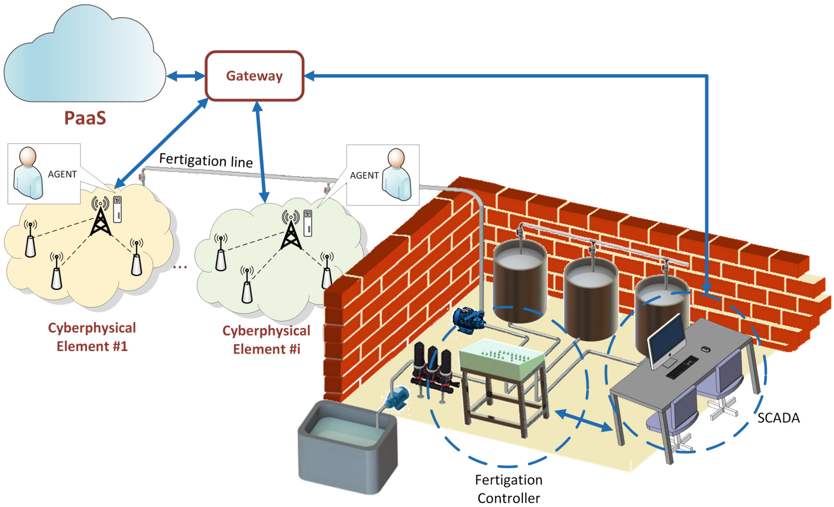

Fig. 6. Agent-based fertigation control architecture.

It is the responsibility of each agent to supervise the cyberphysical element state and to determine the fertigation level based on local information sent by the motes. They will also perform some important data analytics such as short-term environmental predictions. The motes information and the local predictions will be sent to a PaaS where this information will be crossed with data provided by meteorological servers in order to compute the irrigation requirements. This information will then be sent to the fertigation controller which, after approval by the grower, will execute the irrigation schedule.

It is expected that, with this architecture, the amount of water and nutrients used in the fertigation process will be reduced since the irrigation schedule will be defined based on the present plant needs, weather and actual substrate conditions forecast and not based on empirical rules.

4 Conclusion

The need of consciously use water resources has become a necessity due to the intensification of water scarcity. Intensive agriculture is one of the major players in water consumption and contamination due to the indiscriminate use of fertilisers and phytopharmaceuticals. This work addresses this problem by presenting a scalable, decentralised monitoring and predictive control system that will be field tested in a fertigation based strawberries growing production plant. The devised strategy relies on the information provided by a set of measurement nodes and using artificial intelligence techniques to compute the daily irrigation schedule. At the present time, we are engaged at developing the motes core hardware and testing the resiliency of the LoRA network in a point-multipoint network architecture. Trials are being conduced in order to define the energy harvesters operating bounds. Future work will address the implementation of the data analytics in the PaaS platform and the agent-based network.

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Anexo C

This book presents, in an integrated form, both the analysis and synthesis of three different types of hidden Markov models. Unlike other books on the subject, it is generic and does not focus on a specific theme, e.g. speech processing. Moreover, it presents the translation of hidden Markov models' concepts from the domain of formal mathematics into computer codes using MATLAB®. The unique feature of this book is that the theoretical concepts are first presented using an intuition-based approach followed by the description of the fundamental algorithms behind hidden Markov models using MATLAB®. This approach, by means of analysis followed by synthesis, is suitable for those who want to study the subject using a more empirical approach.

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J. Boaventura-Cunha graduated in Electronics and Telecommunications Engineering, has a Ph.D. degree in Electrical and Computer Engineering. Presently he is an Associate Professor with habilitation at the UTAD University, a senior researcher at the INESC-TEC and member of IFAC and IEEE. He has coordinated/participated in several national and international research projects aiming the development of new instrumentation, modelling and control technologies applied to agriculture. His research interests include modeling, system identification and adaptive control.

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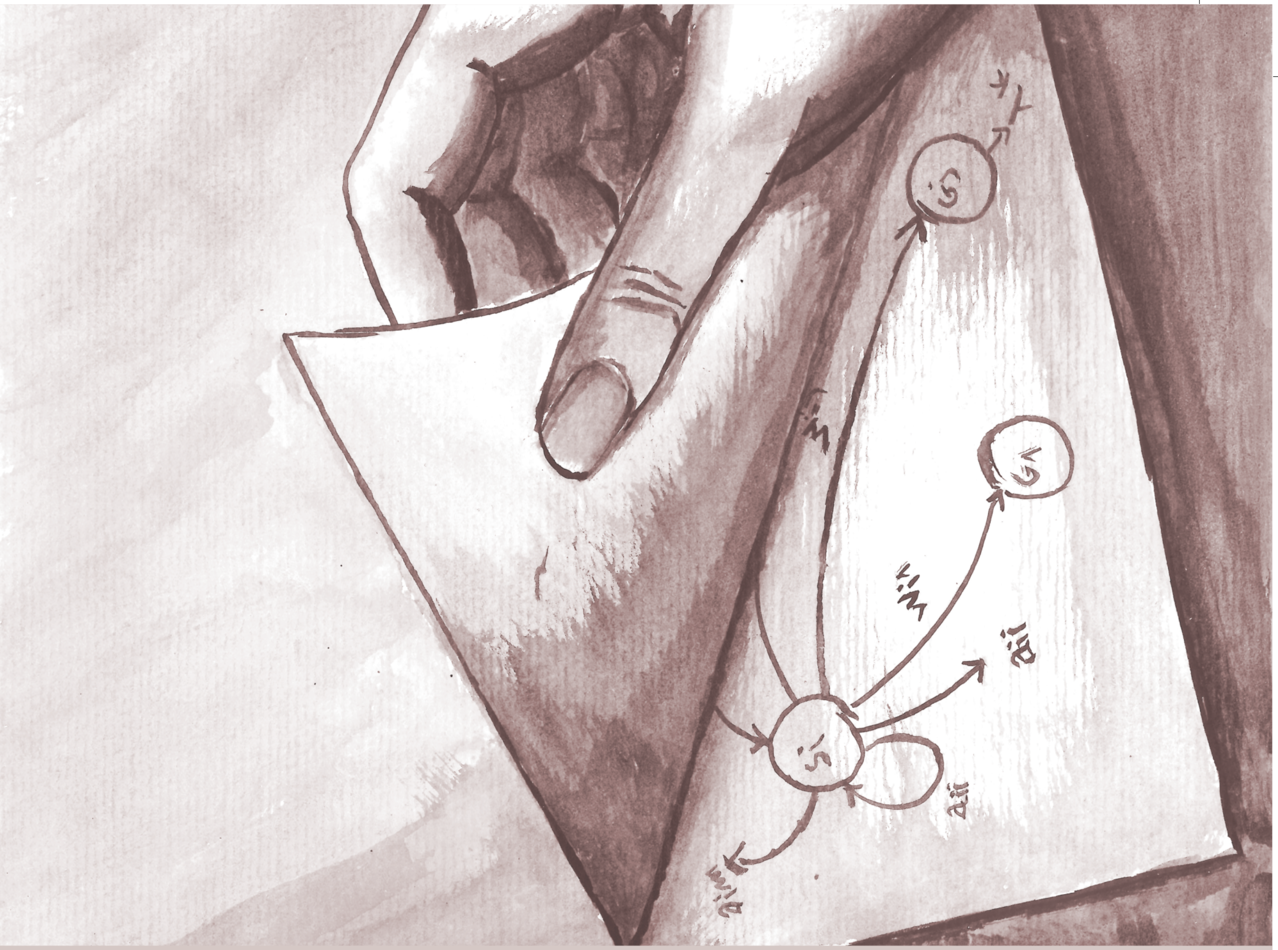

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Preface

> "We are all just cogs in a machine, doing what we were always meant to do, with no actual volition."
>
> —Baron d'Holbach

The quotation above is attributed to Paul-Henri Thiry, Baron d'Holbach, a XVIII century French philosopher. The statement describes, in a very dogmatic and absolute way, the position of d'Holbach regarding the subject of free will versus determinism. This dichotomy of thought is not recent and discussions on this topic date back as far as ancient Greek philosophers. In one hand, it is our internal belief that we are able to choose between distinct courses of action without being driven by any higher force. We don't feel that the future is pre-determined from the beginning of time. Instead, its structure is flexible by nature and can be bent by each and everyone one of us. On the other hand, it is our understanding that the universe is deterministic and, hence, only one course of events is possible. That is, in the limit, we don't have any control on our actions due to the fact that the future is correlated with the past since the beginning of time. Note that this reasoning is in line with the Newtonian interpretation of nature. According to it, the laws that govern everything around us, are deterministic[1]. If two exactly identical rocks are thrown, at different time instants, in the same direction, with the same initial velocity, angle and so on then, according to the Newtonian laws of physics, both will reach the same distance and this distance can be accurately predicted. Now, even if determinism seems counterintuitive when applied to living organisms, it fits better with our knowledge of reality than the concept of free will. Are we so different from rocks?

Suppose that, at a given time instant, we are able to reboot the universe to some arbitrary state. Let this state be, for example, the one derived at the exact

[1] Of course, if we are dealing with the universe at the quantum level, things behave in a very different way. For example the existence of quantum superposition is a reality for subatomic entities. However, quantum effects are diluted when dealing with things at higher levels in the matter scale.

time instant when you have been conceived by your parents. Is it then rational to think that, all the outcomes that follow immediately after this reboot will be the same? That is, you will be created and everything following this event will lead to the exactly same world as the one we are living on right now?

Let's return to our ability to make choices. In our everyday lives, we make hundreds of choices and it seems that we are in charge of all the options made. Can we say that, under the exactly same stimuli, we are able to choose otherwise? Well, if reasoning is an outcome of the brain, and if the brain is a large network of neurons and, at the same time, the neurons always fire in a deterministic fashion whenever submitted to the same stimulus, then probably we are unable to choose differently from the initially picked option. For the sake of argument, let's then assume that free will is unattainable. Can we then predict with exactitude what each and every one of us will do under some condition? This is similar to ask if, in practice, we can predict, with infinite accuracy, where the thrown rock will fall.

The problem is that we must know how each entity will behave under some stimuli, know its initial state or be able to observe and compute a state space which can be prohibitively large and unreachable. So, in short, it is very unlikely that we are able to know, with zero error, what will be the outcome of some event. When asked about the landing point of a thrown rock we can answer something like—"I'm 99% sure that the rock will land at coordinates $(x, y) \pm (\Delta x, \Delta y)$". This means that, due to the universe complexity and processes intertwining, the best thing we are able to do, with more or less certainty, is to guess...

This book deals with this nondeterminism and provides a consistent framework on how to handle a class of very important mathematical models known as hidden Markov models. The main goal is to illustrate the mathematics behind these types of models using intuition and a high level computer language. Having said that, let's begin our voyage.

João Paulo Coelho
Tatiana M. Pinho
José Boaventura-Cunha

Contents

Anexo D

certificado

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7 a 10 de maio 2019

Certifica-se que

João Paulo Coelho

participou na qualidade de palestrante na Mesa Redonda com o tema **Machine Learning** realizado no dia 9 de Maio de 2019 nas instalações do NERBA, em Bragança, Portugal.

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Anexo E

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CERTIFICADO MOOC TÉCNICO

João Paulo Coelho

successfully completed in MOOC Tecnico the following course

Simulação e Controlo de Drones

Arlindo Oliveira

Presidente
Técnico Lisboa

Certificate ID Number: **a07a97155135425e9cb152808bc521a6**

April 8, 2019

TÉCNICO LISBOA

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Técnico Lisboa - droneX

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Anexo F

CERTIFICADO

Certifica-se que **João Paulo Coelho** participou no seminário "O futuro do ensino superior de qualidade é blended e flipped: experiências com o modelo de sala de aula invertida na Universidade de Alcalá – Madrid e a extensão do modelo flipped às universidades espanholas", dinamizado pelo Professor Doutor Alfredo Prieto Martín da Universidade de Alcalá – Madrid, no dia 29 de maio de 2019, na Escola Superior de Tecnologia e Gestão do Instituto Politécnico de Bragança.

ESCOLA SUPERIOR DE TECNOLOGIA E GESTÃO * BRAGANÇA

Professor Doutor Nuno Adriano Baptista Ribeiro

(Diretor da Escola Superior de Tecnologia e Gestão)

INSTITUTO POLITÉCNICO DE BRAGANÇA
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