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UNDER THE HIGH PATRONAGE
OF HIS MAJESTY THE KING OF MOROCCO, MOHAMMED VI



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Table of Contents

An AHP-based Method to Fix Inconsistencies in UML Collaborative Modeling Driss Allaki, Mohamed Dahchour and Abdeslam En-Nouaary (National Institute of Posts and Telecommunications, Morocco, Morocco)	P 1
Cooperation Based Coalition Formation in Distributed Systems Messaouda Ayachi (Dept of Computer Science, University of Bejaia, Algeria), Hachem Slimani (LIMED Laboratory Dept of Computer Science, University of Bejai, Algeria) and Hassina Nacer (Dept of Computer Science, University of Sciences and Technologies Houari Boumedienne, Algeria)	P 6
Towards A Language Interface Design to coordinate between Heterogeneous DSMLs Naima Essadi and Adil Anwar (Siweb Team Research, EMI, Mohamed V University, Morocco)	P 12
Institutional arrangement in the implementation of government's ESB: the case of Indonesia Agung Darono (Ministry of Finance of Republic of Indonesia, Indonesia)	P 16
Parallel Implementation of PrePost Algorithm Based on Hadoop for Big Data Yassir Rochd and Imad Hafidi (IPOSI Laboratory Hassan I University, Morocco)	P 24
Towards Exploring Context to Insure Fault Tolerance in Home Automation Medical System Meriem Zaiter (Larbi Ben M'hidi University of Oum El-Bouaghi, LIRE Laboratory at Abdelhamid Mehri University of Constantine 2, Algeria) Salima Hacini (LIRE Laboratory at Abdelhamid Mehri University of Constantine 2, Algeria) and Moussa Guedrez (BDL Bank, Algeria)	P 29
ABAC Conceptual Graph Model for Composite Web Services Nabil Djebari(LIMED Laboratory Computer Science Departement University of Bejaia, Algeria) Hassina Nacer (MOVEP Laboratory, Computer Science Department USTHB, Algeria) Djamil Aissani (LAMOS laboratory, Operational Research Department University of Bejaia, Algeria) Hachem Slimani (LIMED Laboratory, Computer Science Departement University of Bejaia, Algeria) and Beghdad Bey Kadda (Informatics Systems laboratory, Ecole Militaire Polytechnique, Algeria)	P 36
BPMN Profile for Collaborative Business Process Leila Amdah and Adil Anwar (Siweb Team Research EMI, Mohamed V University, Morocco)	P 42
Autonomous SLAs Negotiation based on Agreement-Broker: Services Availability Zineb Bakraouy, Amine Baina and Mostafa Bellafkih (INPT, National Institute of Posts and Telecommunications, Morocco)	P 48
Towards a New Meta-model of IoTs Interoperability Rachida Ait Abdelouahid, Abdelaziz Marzak and Nawal Sael (Hassan II University of Casablanca- Faculty of science Ben M'sik, Laboratory of technology of information and modeling, Morocco)	P 54

Constraint based Testing and Verification of Java Bytecode Programs Safaa Achour and Mohammed Benattou (LASTID Laboratory, Ibn Tofail University)	P 64
Scalable and Real-time time series Analytics : Telemedicine as use case Abdelilah Bouslama, Yassin Laaziz and Abdelhak Tali (LABTIC ENSA Tanger, Abdelmalek Essaadi University, Morocco)	P 70
The road safety information systems appropriate to the systemic approach: the case of Morocco Nassima Laaraj, Fouad Jawab and Said Boutahari (Laboratory of Energy & Sustainable Development (LPE2D), EST, Sidi Mohamed Ben Abdellah University, Morocco)	P 74
Data Lifecycle: From Big Data to Smart Data Mohammed El Arass (Mohammed V University, EMI-SIWEB Team, Morocco) and Nissrine Souissi (Ecole Nationale Supérieure des Mines, Computer Science Department, Morocco)	P 80
Visualizing an Emerging Mobility Business Ecosystem Anne Faber, Maximilian Riemhofer, Adrian Hernandez-Mendez and Florian Matthes (Department of Informatics Technical, University of Munich, Germany)	P 88
Testing rules for Mapreduce frameworks Sara Hsaini, Salma Azzouzi and My El Hassan Charaf (Laboratory of Informatics Systems and Optimization (ISO) Faculty of sciences, Ibn Tofail University, Morocco)	P 94
Transforming inheritance with constraints from XML schema to ODL schema Doha Malki and Bahaj Mohamed (Department of Mathematics and Computer Science, University Hassan 1st, Morocco)	P 99
Dynamic Data Sensitivity Access Control in Hadoop Platform Hafsa Ait Idar, Khalid Aissaoui, Hicham Belhadaoui and Reda Filali Hilali (CED Engineering Science, ENSEM, Lab. RITM/ESTC, Hassan II University, Morocco)	P 105
Capitalization of knowledge through ontologies: A Knowledge Management approach in a strategic intelligence process Majda Nabigh (Ecole Doctorale Abbé-Grégoire, CNAM, France) and Najima Daoudi (Lyrica Laboratory at ESI and SSL Laboratory at ENSIAS, Maroc)	P 110
Managing model conflicts in collaborative modeling using Constraint Programming Manar Zerrouk (Siweb, EMI, Mohamed V University, Morocco) Adil Anwar (Siweb, EMI, Mohamed V University, Morocco) and Imade Benelallam (SI2M, INSEA, Mohamed V University, Morocco)	P 117
Adaptation of the Value Stream Mapping (VSM) For the Moroccan Artisanal Enterprise Describing a new procedure and parameters of VSM for wood craft enterprise: case study Fatine Chouraf and Anas Chafi (Laboratoire Techniques Industrielles, CED: Sciences et techniques de l'ingénieur, FST FEZ, Morocco)	P 124

<p>Deconflicting policies in attribute-based access control systems</p> <p>Mohamed Yahiaoui, Ahmed Zinedine and Mostafa Harti (Faculty of sciences FSDM USMBA University Fez, Morocco)</p>	P 130
<p>Configurable Process Mining: Variability Discovery Approach</p> <p>Rabab Sikal (AlQualsadi research team, ENSIAS, Mohammed V University of Rabat, Morocco) Hanae Sbai (Faculty of Science and Technology, University Hassan II, Morocco) and Laila Kjiri (AlQualsadi research team, ENSIAS, Mohammed V University of Rabat, Morocco)</p>	P 137
<p>Ontology based on electronic payment fraud prevention</p> <p>Ahmed El Orche, Mohamed Bahaj and Soumya Ain Alhayat (Faculty of Sciences & Technologies HASSAN 1 / Department of Computer and Information Science, Morocco)</p>	P 143
<p>Context Aware Recommender Systems for Tourism: A Concise Review</p> <p>Asmae Bentaleb (LGS, National School of Applied Sciences Ibn Tofail University, Morocco) Younes El Bouzekri (LGS, National School of Applied Sciences Ibn Tofail University, Morocco) Ayoub Ait Lahcen (LGS, National School of Applied Sciences Ibn Tofail University LRIT, Faculty of Science Mohammed V University, Morocco) and Mohammed Boulmalf (International University of Rabat, Morocco)</p>	P 149
<p>Recommendation system based on data analysis Application on tweets sentiment analysis</p> <p>Sana Nabil, Jaber Elbouhdidi and Mohamed Yassin Chkouri (SIGL Team ENSA Tétouan ABDELMALEK SAADI University, Morocco)</p>	P 155
<p>Deep Learning Based Recommender Systems</p> <p>Brahim Ouhbi (LM2I Laboratory, ENSAM Meknes Moulay Ismaïl University, Morocco) Bouchra Frikh (LTTI Laboratory, EST Fès Sidi Mohamed Ben Abdellah University, Morocco) El Moukhtar Zammouri (LM2I Laboratory, ENSAM Meknes Moulay Ismaïl University, Morocco) and Abdellwahed Abbad (LTTI Laboratory, EST Fès Sidi Mohamed Ben Abdellah University, Morocco)</p>	P 161
<p>Data Mining approach for modeling Murabaha Return Risk taking into account Economic Factors</p> <p>K Chelhi (Faculty of Sciences Ben M'Sik, University Hassan II, Morocco) M El Hachloufi (Faculty of Law, Economics Ain Sebaâ, University Hassan II, Morocco) M. Elfar (Faculty of Sciences, Dhar El Mahraz, University Sidi Mohammed Ben Abdellah, Morocco) A Eddaoui (Faculty of Sciences Ben M'Sik, University Hassan II, Morocco) and A Marzak (Faculty of Sciences Ben M'Sik, University Hassan II, Morocco)</p>	P 167
<p>Archiving and retrieving digital elaborations of ancient manuscripts</p> <p>Pasquale Savino, Anna Tonazzini, Franca Debole and Emanuele Salerno (ISTI-CNR Pisa, Italy)</p>	P 172
<p>Feature Selection Applied to G.729 Synthesized Speech for Automatic Speaker Recognition</p> <p>Kawthar Yasmine Zergat (Speech Com. and Signal Proc. Lab.-LCPTS Faculty of Electronics and Computer Sciences, USTHB, Algeria) Sid Ahmed Selouani (Department of Information Management, University of Moncton, Canada) and Abderrahmane Amrouche (Speech Com. and Signal Proc. Lab.-LCPTS Faculty of Electronics and Computer Sciences, USTHB, Algeria)</p>	P 178

Word RNN as a Baseline for Sentence Completion	P 183
Heewoong Park, Sukhyun Cho and Jonghun Park (Dept. of Industrial Engineering & Center for Superintelligence, Seoul National University, Republic of Korea)	
A first step towards NLP from digitized manuscripts: virtual restoration	P 188
Franca Debole, Muhammad Hanif, Emanuele Salerno, Pasquale Savino and Anna Tonazzini (Institute of Information Science and Technologies Italian National Research Council, Pisa, Italy)	
Semantic Analysis of Arabic Texts within SAFAR Framework	P 194
Mohammed Nasri (National School of Applied Sciences, Hassan I University, Morocco) Younes Jaafar (Mohammadia School of Engineers, Mohammed V University, Morocco) and Karim Bouzoubaa (Mohammadia School of Engineers, Mohammed V University, Morocco)	
Link Prediction in Dynamic Social Networks: A Literature Review	P 200
Mohammad Marjan, Nazar Zaki and Elfadil Mohamed (United Arab Emirates University, Ajman university, United Arab Emirates)	
Identifying Corroborated and Contradicted Claims Among Witness Statements using Post-Hoc Collective Intelligence	P 208
Dean Jones and Gunjan Mansingh (Department of Computing The University of the West Indies Mona, Jamaica)	
Scanning is Just the Beginning: Exploiting Text and Language Technologies to Enhance the Value of Historical Manuscripts	P 214
Angelo Mario Del Grosso, Andrea Bellandi, Emiliano Giovannetti, Simone Marchi and Ouafae Nahli (Institute of Computational Linguistics "Antonio Zampolli", Italian National Research Council (ILC-CNR), Italy)	
A review of machine learning algorithms for web page classification	P 220
Safae Lassri, El Habib Ben Lahmar and Abderrahim Tragha (laboratory information technology and modeling Ben M'sik Faculty of Science, Hassan II University, Morocco)	
Visualizing and Transcribing Complex Writings through RTI	P 227
Federico Ponchio(CNR-ISTI Pisa, Italy) Marion Lame (CNR-ISTI and UMR 7324 CITERES-LAT Pisa, Italy and Tours, France) Roberto Scopigno (CNR-ISTI Pisa, Italy) and Bruce Robertson (Classics, Mount Allison University Sackville, NB, Canada)	
Feature Selection Based on Graph Representation	P 232
Yassine Akhiat, Mohamed Chahhou and Ahmed Zinedine (LIMS Laboratory Faculty of sciences, USMBA, Morocco)	
Formalization of the Maçdar category by its patterns using the NooJ platform	P 238
Ahmed Bounoua, Ahmed Zinedine and Mohammed El Mohajir (Faculty of Sciences, USMBA Fez, Morocco) Mohamed El Hannach (International Agency for NLP IA4NLP)	

Benefits of morphosyntactic features on English-Arabic Statistical Machine Translation	P 244
Safae Berrichi and Azzeddine Mazroui (Department of computer Science Faculty of Sciences, University Mohamed First, Morocco)	
Opinion and sentiment polarity detection using supervised machine learning	P 249
Ibtissam Touahri and Azzeddine Mazroui (Department of Computer Science Faculty of Sciences, University Mohamed First, Morocco)	
Arabic language alignment with English ontologies - Some ontological reflections	P 254
Ouafae Nahli (Institute for Computational Linguistics "Antonio Zampolli" Italian National Research Council, Italy)	
Statistical Machine Translation for Bilingually Low-Resource Scenarios: A Round-Tripping Approach	P 261
Benyamin Ahmadnia (Autonomous University of Barcelona Cerdanyola del Valles, Spain) Gholamreza Haffari (Monash University Clayton, VIC, Australia) and Javier Serrano (Autonomous University of Barcelona Cerdanyola del Valles, Spain)	
Qohelet Euphoria: a Domain Specific Language to Annotate Multilingual Variant Readings	P 266
Luigi Bambaci (Dipartimento di Civiltà e Forme del Sapere Università di Pisa, Italy) Federico Boschetti (CoPhiLab Istituto di Linguistica Computazionale "A. Zampolli", CNR Pisa, Italy) and Riccardo Del Gratta (LaRI Istituto di Linguistica Computazionale "A. Zampolli", CNR Pisa, Italy)	
Arabic Sentiment analysis using a Levenshtein Distance Based Representation Approach	P 270
Basma Essatouti (ADMIR Lab, IRDA Team, Rabat IT Center, Morocco) Hakima Khamar (ALEM Team, EMI, Rabat IT Center, Mohammed V University, Morocco) Sanaa El Fkihi (ADMIR Lab, IRDA Team, Rabat IT Center, Morocco) Rdouan Faizi (ADMIR Lab, IRDA Team, Rabat IT Center, Morocco) and Rachid Oulad Haj Thami (ADMIR Lab, IRDA Team, Rabat IT Center, Morocco)	
Audio-Visual Synchronisation in Quantum Movies	P 274
Fei Yan (School of Computer Science and Technology Changchun University of Science and Technology, China) Abdullah Iliyasa (Electrical Engineering Department Prince Sattam Bin Abdulaziz University Al-Kharj, Kingdom of Saudi Arabia) Sihao Jiao (School of Computer Science and Technology Changchun University of Science and Technology, China) and Huamin Yang (School of Computer Science and Technology Changchun University of Science and Technology, China)	
Comparative Study of Color Image Segmentation by the Seeded Region Growing Algorithm	P 279
Rajaa Charifi, Najia Essbai, Anass Mansouri and Yahya Zennayi (School of Sciences and Technologies, LERSI, University Sidi Mohammed Ben Abdellah, Embaded System Department, Mascir, Morocco)	
New approach for Arabic characters recognition based on the «Hough Transform»	P 285
M'barek Nasri and Mohammed Kadi (Laboratory MATSI, EST, Mohamed I University, Morocco)	
Hybrid Segmentation Method for Grayscale Images	P 290

Hanane Barraah and Abdeljabbar Cherkaoui
(Laboratory of Innovative technologies National School of Applied Sciences Tangier, Morocco)

Texture classification via attractive-and-repulsive decoded gradient contours P 296

Issam El Khadiri, Mohamed Kas, Youssef El Merabet and Raja Touahni (Laboratoire LASTID, Département de Physique Faculté des Sciences, Université Ibn Tofail, Maroc)
and Yassine Ruichek (Le2i FRE2005, CNRS, Arts et Métiers Univ. Bourgogne Franche-Comté, UTBM, France)

A comparison of some contour based shape descriptors after applying Bezier curve approximation with application to Brachiopods classification P 302

Youssef Ait Khouya (Qualifying High School, Alhidaya Islamiya, Ministry of National Education, Morocco)
and Faouzi Ghorbel (GRIFT Research Group, CRISTAL Laboratory, National School of Computer Sciences University of Manouba, Tunisia)

Single core SIMD parallelization of GMM background subtraction algorithm for vehicles detection P 308

Lhousein Mabrouk, Dominique Houzet, Sylvain Huet (CNRS, Grenoble-INP, GIPSA-Lab Univ. Grenoble, France)
Said Belkouch, Abdelkrim Hamzaoui (LGEOS Lab, ENSA Marrakech Cadi Ayyad University, Morocco)
and Yahya Zennayi (Embedded systems Lab Mascir Foundation, Morocco)

Vehicle Type Classification Using Convolutional Neural Network P 313

Hicham Bensedik, Ahmed Azough and Mohammed Meknassi
(Laboratory of Informatics and Modelization Faculty of Science Dhar Mehraz, Morocco)

Fuzzy Hamming distance and Perfect Face Ratios based Face Sketch Recognition P 317

Khalid Ounachad, Abdelalim Sadiq and Abdelghani Souhar
(Department of Informatics Faculty of sciences, Ibn Tofail University, Morocco)

Comparative Study of Different Association Rule Methods P 323

Otmane Stit, Jamal Riffi, Ali Yahyaouy and Hamid Tairi
(LIAN, Faculty of Sciences Dhar el Mahraz, Morocco)

Smart courses recommender system for online learning platform P 328

Karim Dahdouh, Ahmed Dakkak, Lahcen Oughdir (LSI, Department of Mathematics, Physics, and Informatics Sidi Mohamed Ben Abdellah University, FPT Taza, Morocco)
and Abdelali Ibriz (High School of Technology Sidi Mohamed Ben Abdellah University, Morocco)

A Survey of Pedagogical Affordances of Augmented and Virtual Realities Technologies in IoT-Based Classroom P 334

Houda Elkoubaiti and Radouane Mrabet
(Smart Systems Laboratory, ENSIAS, Mohammed V University, Morocco)

A proposed design process of a customized educational hybrid prototyping machine P 342

Jihad El Mesbahi, Ahmed Rechia, Abdelilah El Mesbahi (Laboratory of Engineering , Innovation and Industrial Management Systems Faculty of Sciences and Techniques Tangier, Morocco)

and Jihane Kojmane (Laboratory of mechanical engineering Faculty of Sciences and Techniques Fes, Morocco)

Integrating MOOCs in Traditional Classrooms for higher education: experimental study in Chouaib Doukkali University P 348

Fatima Lakrami, Ouidad Labouidya and Najib ElKamoun (STIC Laboratory departmenet of Physics Faculty of science Chouaib Doukkali universiti EL Jadida, Morroco)

Case-Based Reasoning for E-learning Systems: State of the art P 353

Soundouss Abroun (Abdelmalek Essaidi University FSTT, Laboratory of Computer Science, Systems and Telecommunications, Morocco)

Mohamed Ghailani (Abdelmalek Essaidi University ENSAT LabTIC Laboratory, Morocco) and Abdelhadi Fennan (Abdelmalek Essaidi University FSTT, Laboratory of Computer Science, Systems and Telecommunications, Morocco)

The Effect of Using Computerize Software to Solving the Problem of Fractions Learning : Case Study: Economic Course P 357

Feras Hamed Zahda and Motasem na'eem Natsheh (College of Applied Professions, Polytechnic University (PPU) Hebron, Palestine)

Knowledge Management to Support Learning Analytics in Higher Education P 362

Abdullah Alenezi, Christos Emmanouilidis and Ahmed Al-Ashaab (School of Aerospace, Transport and Manufacturing Cranfield University Cranfield, UK)

Simple Spirited Scalable E-Learning System P 368

Soma Datta (Software Engineering University of Houston Clear Lake Houston, TX, USA) and Swati Bhattacharyya (Research Services, Library University of California Riverside Riverside,CA, USA)

How to Analyze the Overall Performance of a Student: Strong or Weak P 374

Monalisa Dey, Anupam Mondal and Dipankar Das (Computer Science and Engineering Jadavpur University Kolkata, India)

Designing an IMS-LD Model for Collaboration Space of Learning Management System P 380

Mohammed Ouadoud (UAE, Faculty of Sciences (FS) Laboratory of Informatics, Research Operational and Statistic Applied (LIROSA), Morocco)
Nouha Rida (Computer and Education Research Laboratory Mohammed V University, Mohammadia School of engineering, Morocco)
and Mohamed Yassin Chkouri (UAE, National School of Applied Sciences Laboratory of the Information System and Software Engineering(SIGL), Morocco)

A Heuristic Evaluation of an Educational Game for Children with Dyslexia P 386

Nihal Ouherrou, Fatimaezzahra Benmarrakchi, Oussama El Hammoumi and Jamal El Kafi (Computer Science dept, Chouaib Doukkali University El Jadida, Morocco)

Mobile Graphical User Interface with People with Verbal Communication Disorders P 391

Nikolay Pavlov(Faculty of Mathematics, Informatics and Information Technologies Plovdiv University "Paisii Hilendarski" Plovdiv, Bulgaria)
Yanica Chukanska (S-Ivenna Plovdiv, Bulgaria)
Nevena Mileva (Faculty of Physics and Technology Plovdiv University "Paisii Hilendarski" Plovdiv, Bulgaria)

Manuel Castro, Clara Maria Pérez and María José Albert (UNED Madrid, Spain)

The TESI Project: An Adaptative Personalized System for creating Expression Tools in Social Inclusion of disadvantage learners P 396

María Jose Albert (Educational Theory and Social Pedagogy Faculty of Education, UNED Madrid, Spain)

Clara Pérez-Molina (Dept. Electrical and Computer Engineering (ETSII) UNED Madrid, Spain)

María José Mudarra (Dept. Assessment and Research Methods in Education (Educational Guidance) Faculty of Education, UNED Madrid, Spain)

María García-Pérez (Educational Theory and Social Pedagogy Faculty of Education, UNED Madrid, Spain)

Manuel Castro (Dept. Electrical and Computer Engineering (ETSII) UNED Madrid, Spain)

Nikolay Pavlov (Faculty of Mathematics and Informatics Plovdiv University "Paisii Hilendarski" Plovdiv, Bulgaria)

and Nevena Mileva (Plovdiv University "Paisii Hilendarski" Plovdiv, Bulgaria)

Quality in the Mobile Digital Resources (MDR) Conceptual Model P 398

María José Albert (dept. Teoría de la Educación y Pedagogía Social School of Education, UNED Madrid, Spain)

Clara Pérez-Molina (DIEECTQAI Industrial Engineering Technical School (ETSII) UNED Madrid, Spain)

María García-Pérez (Teoría de la Educación y Pedagogía Social School of Education, UNED Madrid, Spain)

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and Manuel Castro (DIEECTQAI Industrial Engineering Technical School (ETSII) UNED Madrid, Spain)

BCI for assessing the emotional and cognitive skills of children with special educational needs 400

Anna Lekova, Maya Dimitrova, Snezhanka Kostova (Institute of Robotics, Bulgarian Academy of Sciences Sofia, Bulgaria)

Omar Bouattane (ENSET, University Hassan II de Casablanca, Casablanca, Morocco)

and Leire Ozaeta (University of the Basque Country, UPV/EHU San Sebastian, Spain)

ReadLet: Reading for Understanding P 404

Marcello Ferro, Claudia Cappa, Claudia Marzi, Ouafae Nahli, Franco Alberto Cardillo, Vito Pirrelli (ILC CNR, Italy)

and Sara Giulivi (DFA-SUPSI, Switzerland)

The Effectiveness of Development Skills Plan Framework for Learning Disabilities Children: A Systematic Literature Review P 410

Zahidah Zulkifli (Kulliyyah of Information and Communication Technology, International Islamic University Malaysia Kuala Lumpur, Malaysia)

Ely Salwana Mat Surin (Institute of Virtual Informatics (IVI), Universiti Kebangsaan Malaysia Kuala Lumpur, Malaysia)

and Abdul Wahab Abdul Rahman (Department of Computer Science Kulliyyah of Information and Communication Technology, International Islamic University Malaysia Kuala Lumpur, Malaysia)

The Use of ICT in Dealing with Learning Disabilities: A Literature Review with a focus on Reading Arabic Texts P 415

Mohamed Aymane Sbai, Maha El Biadi (Research Group ICT in Higher Education Laboratory of Languages, Literature, Communication and Didactics Faculty of Letters and Human Sciences Dhar Mehraz, Sidi Mohamed Ben Abdellah University, Fez, Morocco)

Mohammed El Mohajir (Laboratory of Informatics, Modeling and Systems, Faculty of Sciences Dhar Mehraz, Sidi Mohamed Ben Abdellah University, Fez, Morocco)

and Ouafae Nahli (Institute for Computational Linguistics, CNR, Pisa, Italy)

Adaptive Dialogue System for Disabled Learners: Towards a Learning Disabilities Model P 422

Mohammed Taouil, Ahlame Begdouri and Aicha Majda

(SIA - Faculty of Sciences and Technology of Fez University of Sidi Mohamed Ben Abdellah Fez, MOROCCO)

Systematic Review: OER and disability P 428

Nidia Moreno, Edmundo Tovar Caro and Rosa Cabedo

(Universidad Politécnica de Madrid Spain)

Text-To-Speech technology for Arabic language learners P 432

Oumaima Zine, Abdelouafi Meziane and Meryem El Hadi

(Department of Mathematics and Computer Science, Mohammed First University, Oujda, Morocco)

Dynamic Fuzzy Asset Management for Worst Scenarios with Average Value-at-Risks P 437

Yuji Yoshida (Faculty of Economics and Business Administration, University of Kitakyushu, Japan)

Empirical Path Loss Models Optimization for Mobile Communication P 443

Houcine Oudira, Lotfi Djouane and Messaoud Garah

(University of Mohammed Boudiaf Laboratory of electrical engineering M'Sila, Algeria)

Wind Turbine Doubly-Fed Asynchronous Machine Diagnosis Defects -part two P 449

Fatima El Hammouchi, Lamia El Menzhi, Abdallah Saad, Yasmine Ihedrane and Badr Bossoufi

(National Higher School of Electricity and Mechanic, Hassan II University, Morocco)

Solar Cell Parameters Extraction of Photovoltaic Module Using Nelder-Mead Optimization P 455

Houcine Oudira, and Amar Mezache (Département d'Electronique, Université Mohamed Boudiaf-M'sila, Laboratoire de Génie Electrique (LGE), Laboratoire SISCO, Algérie)

and Aissa Chouder (Département de Génie Electrique, Université Mohamed Boudiaf-M'sila, Laboratoire de Génie Electrique (LGE), Algérie)

The performance of Decentralized CFAR Detection using Biogeography Based Optimization P 460

Amel Gouri, Amar Mezache (Département d'Electronique, Université Mohamed Boudiaf-M'sila, Laboratoire Analyse des Signaux et des Systèmes, LASS Laboratoire SISCO, Université de Constantine, Algérie)

and Houcine Oudira (Département d'Electronique, Université Mohamed Boudiaf-M'sila, Laboratoire de Génie Electrique (LGE), Algérie)

- Design of Fuzzy Control T-S for Wind Energy Conversion System based PMSG using LMI Approach** P 466
Chakib Chatri and Mohammed Ouassaid
(Engineering for Smart and Sustainable Systems Research Center, Mohammadia School of Engineers, Mohammed V University, Morocco)
- Performance study of the Genetic Algorithm and the Levenverg-Marquardt optimization algorithm for the calibration of a rotating camera** P 472
Mostafa Taibi (Laboratoire Systèmes de Télécommunications et Ingénierie de la Décision (LASTID) Faculté des Sciences Université Ibn Tofail, Maroc)
Rabha Allaoui (dept. Informatique & Télécoms École nationale des sciences appliquées de Khouribga, Maroc)
and Raja Touahni (Laboratoire Systèmes de Télécommunications et Ingénierie de la Décision (LASTID) Faculté des Sciences Université Ibn Tofail, Maroc)
- Optimal Coordination Time Interval for DOCRs in Presence of D-FACTS** P 477
Lazhar Bougouffa and Abdelaziz Chaghi
(El-oued University, Batna-2 University Algeria)
- A pure hardware k-SAT solver for FPGA** P 481
Khadija Bousmar
(Pluridisciplinary Research and Innovation Laboratory (LPRI), Moroccan School of Engineering Science (EMSI), Morocco)
- Design and implementation of greenhouse remote monitor system based on embedded and wireless transmission technologies** P 486
Yasmine Achour (Electrical Systems and Telecommunications Engineering Laboratory, National School of Applied Sciences, Kenitra, Morocco)
Najib El Mernissi (Department of Bio-Technology, Moroccan Foundation for Advanced Science, Innovation and Research, Morocco)
and Driss Zejli (Electrical Systems and Telecommunications Engineering Laboratory, National School of Applied Sciences, Kenitra, Morocco)
- Support Vector Regression Based on Grid-Search Method for Agile Software Effort Prediction** P 492
Abdelali Zakrani, Assia Najm and Abdelaziz Marzak
(dept of Industrial Engineering ENSAM, University of Hassan II, Morocco)
- A study of handling missing data methods for big data** P 498
Imane Ezzine and Laila Benhlima
(Ecole Mohammadia d'Ingénieurs, Mohammed V University, Morocco)
- MoVITS : Moroccan Video Intelligent Transport System** P 502
Omar Bourja, Kaoutar Kabbaj, Hatim Derrouz, Abderrahim El Bouziady, Rachid Oulad Haj Thami, Yahya Zennayi and François Bourzeix
(ADMIR Laboratory, ENSIAS, LRIE Laboratory, Mohammadia School of Engineers, Mohammed V University, Embedded System Department, MAScIR, Morocco)
- An Improvement of Performance in 4G LTE Using Software Defined Network** P 508
Fatima Laassiri (IR2M Laboratory, FST, Univ Hassan UH1, Morocco)
Mohamed Moughit (EEA&TI Laboratory, FST, Univ Hassan, ENSA Khouribga, Univ Hassan 1, Morocco)

and Nouredine Idboufker (National School of Applied Sciences, Univ Cadi Ayyad, Morocco)

Secure Mobility Management using CoAP in the Internet of Things P 514
Brian Oryema, Byeonghoon Lee and Jongtae Park
(School of Electronics Engineering Kyungpook National University Daegu, South Korea)

Performance evaluation of VANETs routing protocols using SUMO and NS3 P 525
Amina Bengag and Mohamed Elboukhari
(MATSI Laboratory, ESTO Oujda, Morocco)

2-D MUSIC Algorithm based on Uniform Triangular Array P 531
Mohammed Amine Ihedrane and Seddik Bri
(Material and Instrumentation (MIN), Electrical Engineering Department, High school of technology ESTM, Moulay Ismail University, Morocco)

Framework for optimizing the charging time of electric vehicles in public supply station deployed in smart cities P 537
Ibrahim El-Fedany, Driss Kiouach (MSTI Team High School of Technology, Ibn Zohr University, Morocco)
and Rachid Alaoui (LASTIMI Laboratory High School of Technology, Mohammed V University, Morocco)

Control of three phase grid connected photovoltaic power systems P 542
Othmane Salama, Abdelmoumen Tabyaoui (LRMI Laboratory Faculty of Science and Technology Settat, Morocco)
and Mohamed Benchagra (LISERT Laboratory National School of Applied Sciences Khouribga, Morocco)

Smart Resident: A Personalized Transportation Guidance System P 547
Mohammad Amin Kuhail, Bilal Ahmad and Collin Rottinghaus
(School of Computing and Engineering University of Missouri-Kansas City Kansas City, MO, US)

Adaptive Traffic Light Control System Using Wireless Sensors Networks P 552
Nouha Rida, Aberrahim Hasbi (Computer and Education Research Laboratory (LRIE) Mohammadia School of Engineers Mohammed V University, Morocco),
Samira Chebli (Laboratory of Systems Analysis, Information Processing Mohammadia School of Engineers Mohammed V University, Morocco)
and Mohammed Ouadoud (UAE, Faculty of Sciences (FS) Laboratory of Informatics, Research Operational and Statistic Applied (LIROSA), Morocco)

Towards Mobile Node Collaboration to Ensure Data Reception in Wireless Sensor Networks P 557
Lyamine Guezouli, Kamel Barka and Souheila Bouam
(LaSTIC Research Lab. University of Batna, Algeria)

Wireless Sensors Network for Traffic surveillance and management in Smart Cities P 562
Anass El Mrini and Abdellatif Ghacham Amrani
(Dept of Physics Laboratory of Science and Advanced Technology Multidisciplinary Faculty of Larache, Morocco)

Optimal Shared Multicast Tree based solution for Group Key Management in mobile IPv6 P 567
Youssef Baddi (ESTSB, UCD, El Jadida, Morocco)

and Mohamed Dafir El Kettani (ENSIAS Mohammed V University, Morocco)

Performance Evaluation of IEEE 802.11p and IEEE 802.16e for Vehicular Ad hoc Networks using simulation tools P 573

Said Benkirane (SAEDD Lab, High School of Technology, Cadi Ayyad University, Essaouira, Morocco)

and Mohamed Benaziz (National School of Arts and Crafts, Moulay Ismail University, Meknes, Morocco)

City logistics problems' identification: A first step toward an analysis approach P 578

Soukaina Aziz, Rachid Benmoussa and El Hassan Irhirane

(Sylpro, ENSA Marrakech Cadi Ayyad University Marrakech, Morocco)

Detection MITM attack in Multi-SDN Controller P 583

Anass Sebbar, Mohammed Boulmalf , Mohamed Dafir El Kettani and Youssef Baddi

(ELIT-Internationale University of Rabat, ENSIAS-Mohammed V Rabat University, Université Chouaib Doukkali, Morocco)

SDN-based solution to Improve IOT: Survey P 588

Hamza Zemrane (Mohammadia School of Engineering Department of Computer Engineering, Lab RIME, Morocco)

Youssef Baddi (lab STIC, ESTSB, UCD El Jadida, Morocco)

and Abderrahim Hasbi (Mohammadia School of Engineering Department of Computer Engineering, Lab RIME, Morocco)

Security challenges in V2I architectures and proposed solutions P 594

Ayoub Toubi and Mazri Tomader

(Department of Electrical Engineering, Networks and Telecommunication Systems. National School of Applied Sciences. Laboratory Engineering of Electrical Systems and Telecommunications, Kenitra, Morocco)

Waijung Blockset-STM32F4 Environment for Real Time Induction Motor Speed Control P 600

Ali Hmidet (Tunis El Manar University, ISTMT ERCO Laboratory, INSAT Tunis, Tunisia)

and Othman Hasnaoui (University of Tunis ERCO Laboratory, INSAT Tunis, Tunisia)

Feasibility study and optimization of a standalone hybrid system for remote area: A case study of High Atlas mountains in Morocco P 606

Abdallah El Zerk, Mohammed Ouassaid (Department of Electrical Engineering Mohammadia School of Engineers, Mohammed V University, Morocco)

and Youssef Zidani (Department of Electrical Engineering, Faculty of science and technology Cadi Ayyad University, Morocco)

Simulation of MANET's single and multiple Blackhole attack with NS-3 P 612

Oussama Sbai and Mohamed Elboukhari

(Department of Applied Engineering, ESTO (Higher School of Technology) Mohammed 1st University, Morocco)

Classification of Mobile Ad Hoc Networks Attacks P 618

Oussama Sbai and Mohamed Elboukhari

(Department of Applied Engineering, ESTO (Higher School of Technology) Mohammed 1st University, Morocco)

- Layer Optimization for Power Reduction in Integrated Circuits** P 625
Lekbir Cherif, Mohamed Chentouf, Jalal Benallal, Mohammed Darmi (1Laboratory of Systems Engineering, National School of Applied Sciences, Ibn Tofail University, ICDS Department, Mentor Graphics, Morocco)
and Rachid Elgouri and Nabil Hmina (Laboratory of Electrical Engineering & Telecommunication Systems National School of Applied Sciences, Ibn Tofail University, Morocco)
- Energy Efficiency analysis in wireless systems by game theory** P 630
Azeddine Riahi (Department of Computer Science, Chouaib Doukkali University , Faculty of Sciences, Morocco)
and Sara Riahi (IMC Laboratory, Department of Physics, Chouaib Doukkali University, Faculty of Sciences, Morocco)
- A network intrusion detection based on improved Nonlinear Fuzzy Robust PCA** P 336
Amal Hadri, Khalid Chougali and Raja Touahni
(LASTID Laboratory Faculty of Science, GREST Research Group, National School of Applied Sciences (ENSA), Ibn tofail University, Morocco)
- RFID Application to Airport Luggage Tracking as a Green Logistics Approach** P 642
Yassir Rouchdi, Achraf Haibi, Khalid El Yassini, Mohammed Boulmalf and Kenza Oufaska
(IA Laboratory, Faculty of Sciences Meknes, Moulay Ismail University, International University of Rabat, TIC Lab, Morocco)
- Vertical and Horizontal Compression Scheme Assessment in Cluster-Based WSNs** P 650
Jihane Elaasri, Samia Al Fallah, Mounir Arioua, Ahmed El Oualkadi and Alia Zakriti
(National School of Applied Sciences, Tetuan, National School of Applied Sciences, Tangier Abdelmalek Essaadi University, Morocco)

ReadLet: Reading for Understanding

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Abstract—This paper focuses on motivation, objectives, design issues and preliminary results of ReadLet, an ICT platform for assessing reading efficiency in primary school children. Test data are discussed on a sample of 200 early graders, reading French, Italian and Standard Modern Arabic (SMA).

Index Terms—Reading, text comprehension, Specific Learning Disorders, multimodal signal processing, cloud computing, portable assistive technology

I. INTRODUCTION

ReadLet is an ICT platform specifically designed to provide accurate, evidence-based assessment of reading efficiency in early grade children. It is intended to offer an ecological, non-invasive protocol for extensive data elicitation, storage and analysis. With Readlet, early graders at school can read a one or two page text displayed on a tablet touchscreen, either silently or aloud. Children are asked to slide their finger across the words as they read, to guide directional tracking. After reading, the child is prompted with a few multiple-answer questions on text content presented one at a time, while the text remains displayed on the screen for the child to be able to retrieve relevant information. In the process, the tablet keeps track of time-aligned multimodal data: voice recording, finger sliding time, time of reading, time of question answering, and number of correct answers. Data are recorded, stored locally, sent to the ReadLet server through an internet connection, and processed remotely by a battery of cloud-based services, analysing data automatically to produce a detailed quantitative signature of each reading session. A server-based database aggregates anonymised data to make them available for specialists. Also individual's longitudinal profiles are stored, for them be queried and inspected upon authorised access. Security issues are addressed by means of secure connections along all the communication paths, and collected data are anonymised to ensure privacy.

II. READLET BACKGROUND MOTIVATION AND RATIONALE

Unlike learning to speak, which develops spontaneously and nearly effortlessly, learning to read requires conscious effort, dedication, focused attention, systematic instruction and corrective error feedback. We still know comparatively little about the basic mechanisms involved in learning to

read fluently and efficiently. Besides, assessing reading skills is an extremely laborious and time-consuming task, which requires monitoring a variety of interlocked abilities, ranging from accurate word rendering, word-in-context reading fluency and lexical access, to linguistic comprehension [1], [2], and interpretation, management and inference of complex events in working memory [3], [4].

To examine levels of reading proficiency in the Mediterranean area and assess appropriate remedial strategies, we started focusing on very different socioeconomic, cultural and linguistic countries such as Italy, Morocco and the Italian speaking area of Switzerland. Results of a study on reading skills carried out in the "Programme for International Student Assessment" (PISA 2012) show that in Italy, on average, about 21% of fifteen-year-old students have poor literacy skills, defined as "understanding, evaluating, using and engaging with written text to participate in society, achieve one's goals and develop one's knowledge and potential". This is in line with evidence that higher education students with early reading problems continue to have specific problems with text comprehension, which become a serious learning issue because of the much higher study load. These figures are bound to increase due to the rising immigration rate to Italy: in 2009, the gap between native students and students with a migrant background was already much higher than in EU countries (72 vs 38 EU-average, the equivalent of about two years of schooling). Similarly, the proportion of adults performing at or below level 1 in Italy is 28%, much higher than the EU-17 average (16.4%) (OECD's PIAAC 2012). In 2007, the Progress in International Reading Literacy Study (PIRLS) Report ranked Morocco in second-to-last place among the participating countries. The same report showed that 74 percent of students do not reach the minimum threshold required to develop their reading skills. A later report (2011) shows an even lower result, with a steadily downward trend in the level of reading of Moroccan students in both primary and secondary education.

On the research front, technological progress in language assessment has considerably advanced our evidence-based knowledge on language abilities [5], [6]. We know that word structure, length, frequency, perceptual salience, age of word acquisition, articulatory complexity, size of lexical neighbourhood and distribution of words in context conspire

to affect children's reading accuracy and speed. Factors and their interaction are understood in considerable detail within labs [7]–[9], but they are elicited and investigated in conditions that are often far from being child-oriented. In many cases, the research focus is on isolated linguistic features and tasks with limited ecological validity (e.g. recognition of phonemes in isolation, naming of images shown on computer screens), coupled with a wide battery of fairly heterogeneous sub-tasks (including general intelligence, non-verbal reasoning, visuo-motor skills, verbal and visual perception among others). Data are elicited in artificially-restrained settings, mostly research and clinical labs with potentially invasive equipment (e.g. eye-trackers). Multi-dimensional responses (e.g. word decoding accuracy, familiarity judgement and comprehension) are typically assessed independently. Besides, the need to control test conditions requires children to be tested in small groups, for a comparatively short time. Text samples are unnaturally short, and behavioural data are typically collected cross-sectionally, as longitudinal samples are more costly and difficult to collect. In our view, a better support to children with reading difficulties requires substantial advances in our understanding of the basic mechanisms involved in learning to read connected texts, as well as better modelling of the dynamic interaction of these mechanisms and their impact on linguistic comprehension in natural reading conditions. All these requirements call for bigger and better data to be collected in naturalistic tasks, in different environments, through multiple modalities, and with minimally invasive equipment.

To meet these requirements, we launched ReadLet, a project leveraging the full potential of ICT methods and tools with the ultimate objective to put in place a ubiquitous infrastructure with a simple tablet as terminal equipment. The infrastructure was designed to deploy and validate ecological screening protocols, portable technology and cloud computing to collect, time-align, integrate and analyse large amount of data of children reading at home or in the classroom. Functional requirements and design issues descended from careful consideration of task protocols, learning and reading models. Technical solutions capitalise on advanced multimodal signal recording and processing technologies, and automated linguistic assessment of text readability. Our methodology intends to establish a virtuous circle between fundamental, knowledge-oriented research on reading and application-oriented research. Reading models are used to design and implement an easy-to-use, low-cost screening technology at the service of real educational and clinical needs. The new technology will be used to collect, store and classify large evidence, which will in turn form the basis of more advanced knowledge, for better reading models to be developed.

A. Reading Models

Reading is not just the ability to assign the correct pronunciation to a sequence of written symbols making up a word (or word decoding), but the joint product of decoding and deep linguistic comprehension [10], [11]. Effective linguistic comprehension relies on language skills such as semantic and syntactic awareness. Both decoding and linguistic comprehension are necessary for reading comprehension, and neither is

by itself sufficient [11]. However, current protocols for reading assessment measure decoding (reading accuracy and speed) and reading comprehension separately [12]–[14]. This does not allow evaluation of reading efficiency [15], defined as the ability to fully understand connected texts by minimising reading time, a cognitive ability that lies at the roots of students' academic achievement [16], [17]. Accordingly, we intend to develop a "Reading Efficiency Model" (REM), which combines decoding accuracy and automaticity (fluency) with reading comprehension. This will be measured by the so-called "Reading Efficiency Parameter" [15] through individual tablet-based test sessions that combine assessment of fluency and reading comprehension. Aspects of REM will be validated with ReadLet acquired data, and will be simulated with machine learning models.

In particular, Bayesian models of reading [18], [19] assume that lexical predictions drive attention in such a way that uncertainty about environmental task-relevant variables is dynamically reduced. This is done either by minimizing entropy, or by minimizing a combination of entropy and eye movement costs (i.e. saccade amplitude). We will use the Bayesian perspective to derive an ideal benchmark, and compare data of children reading performance against it, to discover analogies and differences. At the level of word decoding, we conjecture that in the first learning stages of reading, when letter-to-sound lexical representations are not fully developed and reliable, most input text contributes novel information, with few characters being skipped and lexical representations being frequently revised. When lexical representations get more deeply entrenched and dependable, novelties become rarer, more characters are skipped, reading gets more fluent and effortless, and lexical representations get revised only occasionally [20]. To test these hypotheses algorithmically, hierarchically arranged recurrent neural networks will be used to simulate effects of short-term and long-term memory interaction on different time scales [21]–[24], to replicate predictive reading effects on word, sentence and discourse levels.

III. THE ARCHITECTURE

ReadLet architecture requirements comply with the intended context of use of the proposed platform (Fig. 1). By distributing and mirroring data and processes over a cloud structure, the architecture is guaranteed to be fast and reliable. The user endpoint is a native app for tablet devices. The app is responsible for the administration of the protocol and for the subsequent local recording of finger touch and speech data. Commercial tablet devices can be adopted if equipped with medium-high quality hardware, in terms of touchscreen sensitivity, audio and video acquisition quality, processor performance and storage capacity. To guarantee responsiveness also in off-line mode, the app has a local repository, automatically synchronised with the cloud central repository as the internet connection becomes available. The core of the architecture is a cloud server which exposes a set of functionalities, acting as an interface between the central repository and the users. As new data are stored in the repository, cloud processes are run to perform off-line text, audio, and video processing. Since all multi-modal data are

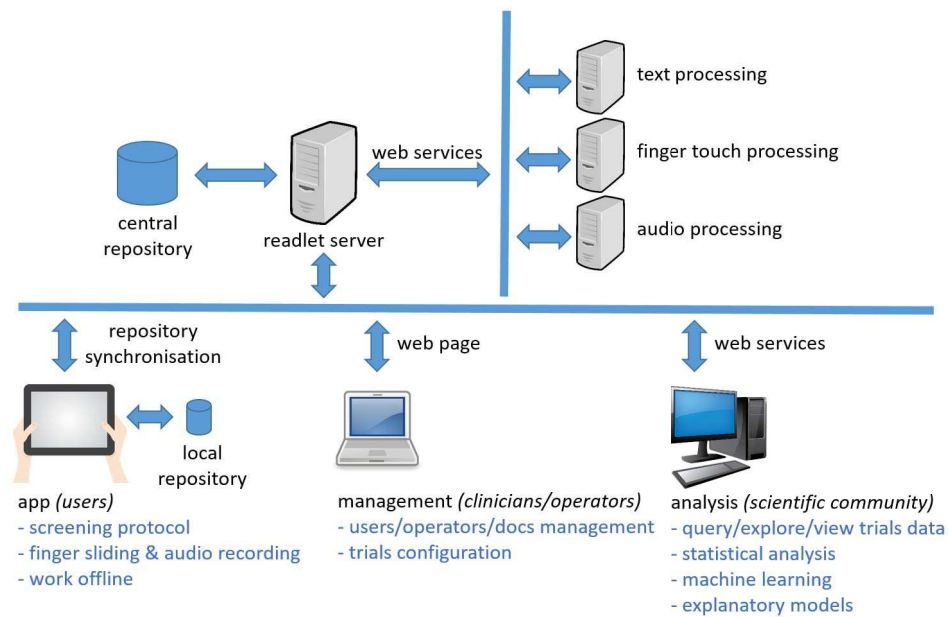


Figure 1. Outline of the ReadLet Functional Architecture

timestamped (i.e. aligned over time), processes can cooperate to make the analysis more robust. Once completed, analysis results are stored back to the central repository, being available for further post-processing. The management interface is a web-application accessed by clinicians and operators to manage the users' profile, to configure the screening sessions, and to manage the documents needed by the screening protocol (e.g. written texts, questionnaires). Recorded data, as well as the result of the cloud off-line data processing, are available to the scientific community through a set of web services provided by the cloud server. This strategy permits the rapid prototyping of third-party applications for data visualisation, analysis and modeling.

The platform combines a number of modality-specific software modules, implemented as web services. They are shortly described in the ensuing sections. At the time of writing, only automated linguistic annotation, readability assessment, finger touch processing and statistical modelling are fully available and in the process of being tested.

A. Text processing and readability assessment

Increasingly sophisticated methods based on Natural Language Processing (NLP) techniques recently allowed the development of computational approaches to the automatic modelling and assessment of text complexity, leading to the estimation of text readability, and the development of advanced readability measures [25]. Unlike traditional metrics (e.g. Flesch–Kincaid or Gulpease tests), which rely on superficial text properties, new NLP-based methods take advantage of a wide range of multi-level linguistic features (e.g. lexical, syntactic, discourse-level) extracted from text and assumed to affect the process of reading comprehension: e.g. abstract or unfamiliar words, non-canonical sentences such as passive

clauses, object relative clauses, 'chains' of embedded sentences etc. For our purposes, ReadLet texts are automatically enriched with multi-level linguistic information and be input to READ-IT [26], an automatic readability assessment tool based on a supervised machine learning approach: given a set of features and a training corpus, READ-IT can create a statistical readability model based on the feature statistics of the training corpus. To assign reliable readability scores to ReadLet texts, we anticipate preliminary training of READ-IT on a corpus of childhood texts classified per age brackets.

B. Speech processing and decoding accuracy

Speech processing technologies can recognise audio recordings of human speech by providing a translation of the acoustic signal into a text, and the temporal alignment of segmented acoustic units with the corresponding text units. Developing children's speech recognition systems is a challenging task, due to lack of data resources and to the wide difference of the acoustic and linguistic characteristics of child speech from those of adult speech, not only at the frequency range level but also in the production modalities (e.g. disfluencies). In fact, the word error rate for children is normally higher than that for adults, even when using an acoustic model trained on child speech [27]. We intend to model child aloud reading, using the new CHILDT2 corpus [28] to improve the recognition performance above an already good Phoneme-Error-Recognition baseline [29]. We anticipate that the speech module will be able to check if a specific read word is rendered correctly, and offer an overall accuracy score for text decoding.

C. Finger touch processing

The touch screen of high-medium quality commercial tablets captures the temporal sequence of touch events of a

finger sliding across the screen with a sampling rate in the 60-120Hz range (corresponding to 12-24 touch events per syllable when reading at 5 syllables per second). When a finger slides across a text displayed on the screen with normal font size, time sequences of touch events can be aligned with letter bounding boxes fairly accurately, by compensating for vertical and horizontal drifts from the current line. Reliable evidence of the child's reading pace can then be derived from the "finger sliding" speed, with speed fluctuations across different text portions, as well as evidence of possible backwards and forwards shifts being accurately recorded. By anchoring finger sliding data on written text, we can associate sliding speed fluctuations with annotated linguistic structures, and with speed, rhythm and prosodic contours of the acoustic signal.

D. Statistical Analysis and Modelling

We expect fluency data to be analysed with established statistical linear models (linear mixed models and generalized additive models), to assess correlations and interactions among standard factors affecting reading performance. In particular, finger sliding data (e.g. per word sliding speed, frequency, average length and duration of sliding regressions) will be entered as dependent variables, and fitted with classical lexical predictors such as word frequency, number of word neighbours, probability distribution of sublexical constituents (e.g. bigrams, morphemes) etc. This will ensure comparability between multimodal reading data for common tasks and by subject groups, and validate statistical models and elicitation protocols cross-modally. Of late, accurate and fast reading of connected text by adults has been shown to have a strong predictive relation to reading comprehension, over and above fluency in reading isolated words [9], [30]. Preliminary results indicate that classical factors (such as word frequency) do not correlate with text reading fluency very well, and that linear analyses of reading speed (such as average word or sentence reading time) can provide only coarse-grained information about reading comprehension. Non-linear analyses of distribution tails and reading time fluctuations prove to fare much better. We will capitalise fully on time-aligned, multimodal reading data of Italian to investigate data interactions between decoding, fluency and text comprehension of early graders with non linear models.

IV. THE PROTOCOL

At the beginning of each reading session, the ReadLet interface prompts to fill in some required information about the reader and the task being administered: a reader identifier, age, grade level, sex, mother tongue, dominant hand, (corrected to) normal vision, language of reading, reading modality etc. A few text formatting parameters can also be set to customise font type, font size, inter-letter space, inter-line space etc. of the text being read (Fig. 2). By clicking a "Start" button, a short text of about two tablet "pages" is displayed full screen. The child is invited to read it, either aloud or silently, while sliding the finger of her/his dominant hand across the text as (s)he reads, to guide directional tracking. A new page is shown

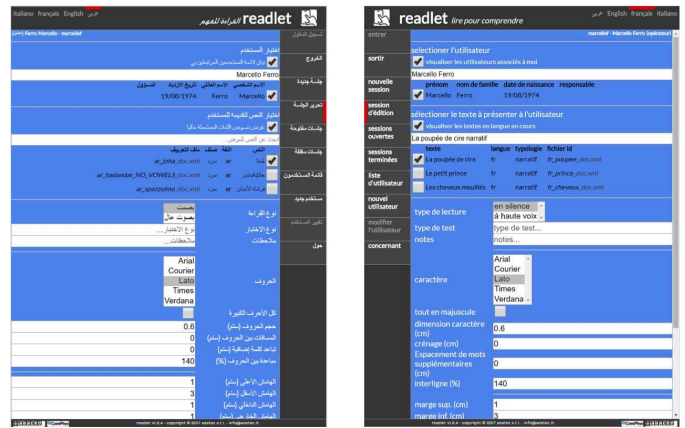


Figure 2. Screenshots of the ReadLet configuration interface for SMA (left) and French (right).

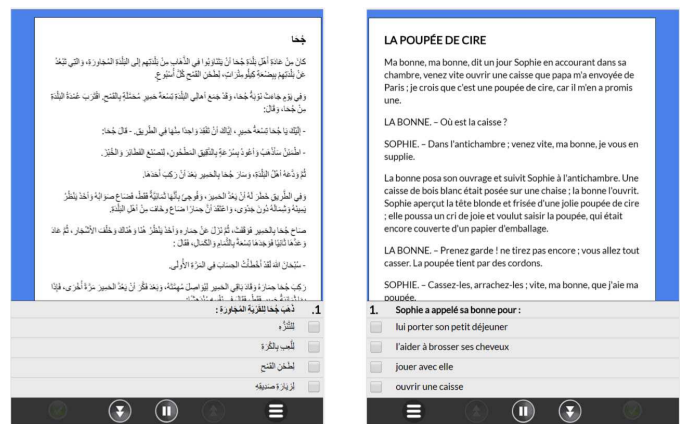


Figure 3. Screenshots of the ReadLet questionnaire interface for SMA (left) and French (right). The text in the background can be scrolled for consultation.

when (s)he clicks a "Continue" button at the end of the current page. When reading is completed, the child is prompted to answer a checkbox questionnaire. One question at a time is shown on the screen, to allow the child to go back to and flip through the text, to look for some relevant information (Fig. 3). When the final question is answered, a short message joyfully informs the child that the task was carried out successfully.

In the process, the tablet keeps track of time-aligned multimodal data: voice recording, finger sliding time, time of reading, time of question answering, and number of correct answers. Data are recorded, stored locally, sent to the ReadLet server through an internet connection, and processed remotely by a battery of cloud-based services, analysing data automatically to produce a detailed quantitative signature of each reading session. As both texts and questions are linguistically annotated and categorised, data on reading performance can be correlated with specific linguistic factors and levels of analysis. A server-based database aggregates anonymised data to make them available for specialists. Also individual's longitudinal profiles are stored, for them be queried and inspected upon authorised access.

V. PROTOTYPE TESTING

Previous experience of administering a pen-and-paper version of the ReadLet protocol to children in the classroom turned out to require specialist assistance for performance assessment, timing and supervision, as well as hours of data post-processing. Moreover, children were reported to show moderate signs of performance anxiety. Preliminary testing of a prototype version of ReadLet technology with a population of about 200 pupils aged 8 to 11, both male and female, varying for socioeconomic status, language (Italian, French and Arabic) and geographical area (Italy, Switzerland and Morocco), showed that children are extremely responsive to using a tablet for reading, and very easy to engage in what they perceive as an enjoyable experience. A preliminary quantitative analysis of ReadLet data reveals a promising correlation with eye-tracking data elicited with more controlled lab-based protocols.

VI. TECHNOLOGICAL, SOCIAL AND ECONOMIC IMPACT

In the long run, ReadLet intends to cover and integrate many language intervention issues, including diagnostic and corrective feedback, therapy, performance monitoring and intelligent decision management, to focus on a wide range of cognitive processes underlying both reading and comprehension. Nowadays, about 50-60% of the workload in childhood/adolescence Neuropsychiatry Units in Italy is devoted to screening children with suspected SLD. Clinical assessment of a single child takes about 6 working hours on average. Only a small percentage of suspected cases (about 15-20%), however, has an SLD diagnosis confirmed. A sophisticated tool for reading assessment able to assign accurate scoring profiles in ecological conditions would significantly reduce wait lists and screening overheads by selecting at-risk cases only, prevent provision of medical care for situations that do not need medical intervention, and improve on the overall quality of medical services, with expectedly lower costs.

With daily sustained usage, the ReadLet platform can also provide therapists with reading data of SLD diagnosed children, make room for more accurate knowledge of the levels of child reading skills, and help deliver the most appropriate treatment. ReadLet text annotation and formatting tools will also help select and deliver text stimuli with controlled and gradually increasing levels of linguistic difficulty, thus supporting more targeted potentiation. We expect this to improve response to treatment, reduce downtime between successive intervention steps, minimise repetition of overlearned tasks, and increase motivation.

Similarly, sustained use of ReadLet protocol in classrooms during normal school hours is likely to increase awareness of reading skills in both pupils and teachers, knowledge about specific factors causing poor reading performance and a more robust relationship between reading confidence and reading performance (this relationship is currently very weak in Italy compared with EU average). We expect both tools and protocols to enable teachers to provide adequate support to all students with reading difficulties, and to monitor and sustain steady literacy progress, regardless of whether children are

officially diagnosed for SLD or not, with a view to promoting more inclusive education and sparser recourse to unnecessary provision of medical assistance. In addition, we expect project results to advance our theoretical understanding of text reading in both at-risk and non problematic conditions, as well as gain deeper insights into what occasionally makes reading difficult and inefficient. In particular, by monitoring both aloud and silent reading in the classroom, specialists will be in a better position to understand at what age and at what level of reading competence, shifting from aloud to silent reading results in better comprehension.

VII. CONCLUDING REMARKS

We believe that technology cannot and should not supplant the role and professional judgement of teachers and therapists in helping children with reading and learning difficulties. Having said that, ReadLet protocols and tools can effectively support daily decisions and education/intervention management, and offer an example of effective introduction of adequate ICT tools into school curricula and daily teaching. From a broader perspective, today's society presents a clear demand for developing coordinated, interdisciplinary efforts in language sciences, implementing a new problem-oriented research life-cycle: i) language and behavioural models will be used in labs to design and implement better technology for language-assessment, addressing real-life issues, ii) outside labs, the new technology will collect larger and richer naturalistic evidence, and iii) the newly collected evidence, structured and classified by NLP tools, can find its way back to labs, for better lexical models to be developed. Such a coordinated effort will target four main objectives: a) sustain interdisciplinary research in lexical modelling; b) coordinate multimodal data creation; c) incentivise technological development for fundamental research, and d) deliver timely application of acquired knowledge and technologies matching real-life need.

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