

ACTAS

DE LAS

XXXVIII Jornadas de Automática

Gijón · Palacio de Congresos · 6, 7 y 8 de Septiembre de 2017



Universidad de Oviedo
Universidá d'Uviéu
University of Oviedo



CEA
Comité Español
de Automática

Colabora

Gijón

Convention Bureau

Actas de

XXXVIII

Jornadas de Automática

© 2017 Universidad de Oviedo
© Los autores

Servicio de Publicaciones de la Universidad de Oviedo
Campus de Humanidades. Edificio de Servicios. 33011 Oviedo (Asturias)
Tel. 985 10 95 03 Fax 985 10 95 07
[http: www.uniovi.es/publicaciones](http://www.uniovi.es/publicaciones)
servipub@uniovi.es

DL AS 2749-2017

ISBN: 978-84-16664-74-0

Todos los derechos reservados. De conformidad con lo dispuesto en la legislación vigente, podrán ser castigados con penas de multa y privación de libertad quienes reproduzcan o plagien, en todo o en parte, una obra literaria, artística o científica, fijada en cualquier tipo y soporte, sin la preceptiva autorización.

Prefacio

Las *Jornadas de Automática* se celebran desde hace **40 años** en una universidad nacional facilitando el encuentro entre expertos en esta área en un foro que permite la puesta en común de las nuevas ideas y proyectos en desarrollo. Al mismo tiempo, propician la siempre necesaria colaboración entre investigadores del ámbito de la Ingeniería de Control y Automática, así como de campos afines, a la hora de abordar complejos proyectos de investigación multidisciplinares.

En esta ocasión, las Jornadas estarán organizadas por la Universidad de Oviedo y se han celebrado del 6 al 8 de septiembre de 2017 en el Palacio de Congresos de Gijón, colaborando tanto la Escuela Politécnica de Ingeniería de Gijón (EPI) como el Departamento de Ingeniería Eléctrica, Electrónica de Computadores y de Sistemas del que depende el Área de Ingeniería de Sistemas y Automática.

Además de las habituales actividades científicas y culturales, esta edición es muy especial al celebrarse el **50 aniversario de la creación de CEA**, Comité Español de Automática. Igualmente este año se conmemora el 60 aniversario de la Federación Internacional del Control Automático de la que depende CEA. Así se ha llevado a cabo la presentación del libro que se ha realizado bajo la coordinación de D. Sebastián Dormido, sobre la historia de la Automática en España en una sesión en la que han participado todos los ex-presidentes de CEA conjuntamente con el actual, D. Joseba Quevedo.

Igualmente hemos contado con la presencia de conferenciantes de prestigio para las sesiones plenarias, comunicaciones y ponencias orales en las reuniones de los 9 grupos temáticos, contribuciones en formato póster. Se ha celebrado también el concurso de CEABOT, así como una nueva Competición de Drones, con el ánimo de involucrar a más estudiantes de últimos cursos de Grado/Máster.

En el marco de las actividades culturales programadas se ha podido efectuar un recorrido en el casco antiguo situado en torno al Cerro de Santa Catalina y visitar la Laboral.

Gijón, septiembre de 2017

Hilario López
Presidente del Comité Organizador

Program Committee

Antonio Agudo	Institut de Robòtica i Informàtica Industrial
Rosa M Aguilar	University of La Laguna.
Luciano Alonso	University of Cantabria
Ignacio Álvarez García	Universidad de Oviedo
Antonio Javier Artuñedo García	Centre for Automation and Robotics (CSIC-UPM)
José M. Azorín	Miguel Hernandez University of Elche
Pedro Balaguer	Universitat Jaume I
Antonio Javier Barragán Piña	Universidad de Huelva
Alfonso Baños	Universidad de Murcia
Guillermo Bejarano	University of Seville
Gerardo Beruvides	Centro de Automática y Robótica
Carlos Bordons	University of Seville
Jose Manuel Bravo	University of Huelva
Jose Luis Calvo-Rolle	University of A Coruña
Fernando Castaño Romero	Centro de Automática y Robótica (UPM -CSIC)
José Luis Casteleiro-Roca	University of Coruña
Alvaro Castro-Gonzalez	Universidad Carlos III de Madrid
Ramon Costa-Castelló	Universitat Politècnica de Catalunya
Abel A. Cuadrado	University of Oviedo
Arturo De La Escalera	Universidad Carlos III de Madrid
Emma Delgado	Universidad de Vigo
Jose-Luis Diez	Universitat Politecnica de Valencia
Manuel Domínguez	Universidad de León
Juan Manuel Escaño	Universidad de Sevilla
Mario Francisco	University of Salamanca
Maria Jesus Fuente	Universidad de Valladolid
Juan Garrido	Universtiy of Cordoba
Antonio Giménez	Universidad de Almeria
Evelio Gonzalez	Universidad de La Laguna
José-Luis Guzmán	Universidad de Almería
Rodolfo Haber	Center for Automation and Robotics (UPM-CSIC)
César Ernesto Hernández	Universidad de Almería
Eloy Irigoyen	UPV/EHU
Agustin Jimenez	Universidad PolitÁcnica de Madrid
Emilio Jiménez	University of La Rioja
Jesus Lozano	Universidad de Extremadura
Jorge Luis Madrid	Centro de Automática y Robótica
Luis Magdalena	Universidad Politécnica de Madrid
David Martin Gomez	Universidad Carlos III de Madrid
Fernando Matia	Universidad Politecnica de Madrid
Joaquim Melendez	Universitat de Girona
Juan Mendez	Universidad de La Laguna
Luis Moreno	Universidad Carlos III de Madrid
María Dolores Moreno Rabel	Universidad de Extremadura
David Muñoz	Universidad de Sevilla
Antonio José Muñoz-Ramirez	Universidad de Málaga
Jose Luis Navarro	Universidad Politecnica de Valencia
Manuel G. Ortega	University of Seville
Andrzej Pawlowski	UNED
Mercedes Perez de La Parte	University of La Rioja
Ignacio Peñarrocha	Universitat Jaume I de Castelló, Spain
José Luis Pitarch	Universidad de Valladolid

Daniel Pérez	University of Oviedo
Emilio Pérez	Universitat Jaume I
Juan Pérez Oria	Universidad de Cantabria
Miguel Ángel Ridao	Universidad de Sevilla
Gregorio Sainz-Palmero	Universidad de Valladolid
Antonio Sala	Universitat Politecnica de Valencia
Ester Sales-Setién	Universitat Jaume I
Jose Sanchez	UNED
Javier Sanchis Saez	Universitat Politecnica de Valencia (UPV)
José Pedro Santos	ITEFI-CSIC
Matilde Santos	Universidad Complutense de Madrid
Alvaro Serna	University of Valladolid
José Enrique Simó	Universidad Politécnica de Valencia
José A. Somolinos	ETS I Navales. Universidad Politecnica de Madrid
Fernando Tadeo	Univ. of Valladolid
Alejandro Tapia	Universidad de Loyola Andalucía
David Tena	Universitat Jaume I
Jesús Torres	Universidad de La Laguna
Pedro M. Vallejo	Universidad de Salamanca
Guilherme Vianna	Universidad de Sevilla
Alejandro Vignoni	AI2 - UPV
Ramón Vilanova	UAB
Francisco Vázquez	Universidad de Cordoba
Jesús M. Zamarreño	University of Valladolid

Revisores Adicionales

Al-Kaff, Abdulla

Balbastre, Patricia
Beltrán de La Cita, Jorge
Bermudez-Cameo, Jesus
Blanco-Claraco, Jose-Luis
Blanes, Francisco
Bonin-Font, Francisco

Cancela, Brais

Ferraz, Luis

Garita, Cesar
Gimenez, Antonio
Gruber, Patrick
Guindel, Carlos

Hernandez Ruiz, Alejandro
Hernandez, Daniel

Jardón Huete, Alberto

López, Amable

Marin, Raul
Marín Plaza, Pablo
Mañanas, Miguel Angel
Morales, Rafael
Moreno, Francisco-Angel

Núñez, Luis Ramón

Ponz Vila, Aurelio
Posadas-Yague, Juan-Luis
Poza-Luján, Jose-Luis
Pumarola, Albert

Raya, Rafael
Revestido Herrero, Elías
Rocon, Eduardo
Ruiz Sarmiento, José Raúl
Ruiz, Adria

Torres, Jose Luis

Vaquero, Victor

Table of Contents

Ingeniería de Control	
<hr/>	
TÚNEL DE AGUA PARA PRUEBAS Y CARACTERIZACIÓN DE DISEÑOS EXPERIMENTALES DE TURBINAS HIDROCINÉTICAS	1
<i>Eduardo Alvarez, Manuel Rico-Secades, Antonio Javier Calleja Rodríguez, Joaquín Fernández Francos, Aitor Fernández Jiménez, Mario Alvarez Fernández and Samuel Camba Fernández</i>	
Reduction of population variability in protein expression: A control engineering approach.	8
<i>Yadira Boada, Alejandro Vignoni and Jesús Picó</i>	
CONTROL ROBUSTO DEL PH EN FOTOBIORREACTORES MEDIANTE RECHAZO ACTIVO DE PERTURBACIONES	16
<i>José Carreño, Jose Luis Guzman, José Carlos Moreno and Rodolfo Villamizar</i>	
Control reset para maniobra de cambio de carril y validación con CarSim	23
<i>Miguel Cerdeira, Pablo Falcón, Antonio Barreiro, Emma Delgado and Miguel Díaz-Cacho</i>	
Maniobra de aterrizaje automática de una Cessna 172P modelada en FlightGear y controlada desde un programa en C	31
<i>Mario de La Rosa, Antonio Javier Gallego and Eduardo Fernández</i>	
Alternativas para el control de la red eléctrica aislada en parques eólicos marinos	38
<i>Carlos Díaz-Sanahuja, Ignacio Peñarrocha, Ricardo Vidal-Albalade and Ester Sales-Setién</i>	
CONTROL PREDICTIVO DISTRIBUIDO UTILIZANDO MODELOS DIFUSOS PARA LA NEGOCIACIÓN ENTRE AGENTES	46
<i>Lucía Fargallo, Silvana Roxani Revollar Chavez, Mario Francisco, Pastora Vega and Antonio Cembellín</i>	
Control Predictivo en el espacio de estados de un captador solar tipo Fresnel	54
<i>Antonio Javier Gallego, Mario de La Rosa and Eduardo Fernández</i>	
Control predictivo para la operación eficiente de una planta formada por un sistema de desalación solar y un invernadero	62
<i>Juan Diego Gil Vergel, Lidia Roca, Manuel Berenguel, Alba Ruiz Aguirre, Guillermo Zaragoza and Antonio Giménez</i>	
Depuración de Aguas Residuales en la Industria 4.0	70
<i>Jesus Manuel Gomez-De-Gabriel, Ana María Jiménez Arévalo, Laura Eiroa Mateo and Fco. Javier Fernández-De-Cañete-Rodríguez</i>	
Control robusto con QFT del pH en un fotobioreactor raceway	77
<i>Ángeles Hoyo Sánchez, Jose Luis Guzman, Jose Carlos Moreno and Manuel Berenguel</i>	
Revisión sistemática de la literatura en ingeniería de sistemas. Caso práctico: técnicas de estimación distribuida de sistemas ciberfísicos	84
<i>Carmelina Ierardi, Luis Orihuela Espina, Isabel Jurado Flores, Álvaro Rodríguez Del Nozal and Alejandro Tapia Córdoba</i>	
Desarrollo de un Controlador Predictivo para Autómatas programables basado en la normativa IEC 61131-3	92
<i>Pablo Krupa, Daniel Limon and Teodoro Alamo</i>	
Diseño de un emulador de aerogenerador de velocidad variable DFIG y control de pitch ...	100
<i>Manuel Lara Ortiz, Juan Garrido Jurado and Francisco Vázquez Serrano</i>	

Observación de la fracción de agua líquida en pilas de combustible tipo PEM de cátodo abierto.....	108
<i>Julio Luna and Ramon Costa-Castelló</i>	
Control Predictivo Basado en Datos.....	115
<i>José María Manzano, Daniel Limón, Teodoro Álamo and Jan Peter Calliess</i>	
Control MPC basado en un modelo LTV para seguimiento de trayectoria con estabilidad garantizada.....	122
<i>Sara Mata, Asier Zubizarreta, Ione Nieva, Itziar Cabanes and Charles Pinto</i>	
Implementación y evaluación de controladores basados en eventos en la norma IEC-61499.	130
<i>Oscar Miguel-Escrig, Julio-Ariel Romero-Pérez and Esteban Querol-Dolz</i>	
AUTOMATIZACIÓN Y MONITORIZACIÓN DE UNA INSTALACIÓN DE ENSAYO DE MOTORES.....	138
<i>Alfonso Poncela Méndez, Miguel Ochoa Vega, Eduardo J. Moya de La Torre and F. Javier García Ruíz</i>	
OPTIMIZACIÓN Y CONTROL EN CASCADA DE TEMPERATURA DE RECINTO MEDIANTE SISTEMAS DE REFRIGERACIÓN.....	146
<i>David Rodríguez, José Enrique Alonso Alfaya, Guillermo Bejarano Pellicer and Manuel G. Ortega</i>	
Diseño LQ e implementación distribuida para la estimación de estado.....	154
<i>Álvaro Rodríguez Del Nozal, Luis Orihuela, Pablo Millán Gata, Carmelina Ierardi and Alejandro Tapia Córdoba</i>	
Estimación de fugas en un sistema industrial real mediante modelado por señales aditivas.	160
<i>Ester Sales-Setién, Ignacio Peñarrocha and David Tena</i>	
Advanced control based on MPC ideas for offshore hydrogen production.....	167
<i>Alvaro Serna, Fernando Tadeo and Julio. E Normey-Rico</i>	
Transfer function parameters estimation by symmetric send-on-delta sampling.....	174
<i>José Sánchez, María Guinaldo, Sebastián Dormido and Antonio Visioli</i>	
An Estimation Approach for Process Control based on Asymmetric Oscillations.....	181
<i>José Sánchez, María Guinaldo Losada, Sebastian Dormido, José Luis Fernández Marrón and Antonio Visioli</i>	
Robust PI controller for disturbance attenuation and its application for voltage regulation in islanded microgrid.....	189
<i>Ramon Vilanova, Carles Pedret and Orlando Arrieta</i>	
Infraestructura para explotación de datos de un simulador azucarero.....	197
<i>Jesús M. Zamarreño, Cristian Pablos, Alejandro Merino, L. Felipe Acebes and De Prada César</i>	
<hr/>	
Automar	
<hr/>	
INFRAESTRUCTURA PARA ESTUDIAR ADAPTABILIDAD Y TRANSPARENCIA EN EL CENTRO DE CONTROL VERSÁTIL.....	203
<i>Juan Antonio Bonache Seco, José Antonio Lopez Orozco, Eva Besada Portas and Jesús Manuel de La Cruz</i>	
ARQUITECTURA DE CONTROL HÍBRIDA PARA LA NAVEGACIÓN DE VEHÍCULOS SUBMARINOS NO TRIPULADOS.....	211
<i>Francisco J. Lastra, Jesús A. Trujillo, Francisco J. Velasco and Elías Revestido</i>	

Exploración y Reconstrucción 3D de Fondos Marinos Mediante AUVs y Sensores Acústicos	218
<i>Oscar L. Manrique Garcia, Mario Andrei Garzon Oviedo and Antonio Barrientos</i>	
AUTOMATIZACIÓN DE MANIOBRAS PARA UN TEC DE 2GdL	226
<i>Marina Pérez de La Portilla, José Andrés Somolinos Sánchez, Amable López Piñeiro, Rafael Morales Herrera and Eva Segura</i>	
MERBOTS PROJECT: OVERALL DESCRIPTION, MULTISENSORY AUTONOMOUS PERCEPTION AND GRASPING FOR UNDERWATER ROBOTICS INTERVENTIONS	232
<i>Pedro J. Sanz, Raul Marin, Antonio Peñalver, David Fornas and Diego Centelles</i>	
<hr/> Bioingeniería <hr/>	
MARCADORES CUADRADOS Y DEFORMACIÓN DE OBJETOS EN NAVEGACIÓN QUIRÚRGICA CON REALIDAD AUMENTADA	238
<i>Eliana Aguilar, Oscar Andres Vivas and Jose Maria Sabater-Navarro</i>	
Entrenamiento robótico de la marcha en pacientes con Parálisis Cerebral: definición de objetivos, propuesta de tratamiento e implementación clínica preliminar	244
<i>Cristina Bayón, Teresa Martín-Lorenzo, Beatriz Moral-Saiz, Óscar Ramírez, Álvaro Pérez-Somarriba, Sergio Lerma-Lara, Ignacio Martínez and Eduardo Rocon</i>	
PREDICCIÓN DE ACTIVIDADES DE LA VIDA DIARIA EN ENTORNOS INTELIGENTES PARA PERSONAS CON MOVILIDAD REDUCIDA	251
<i>Arturo Bertomeu-Motos, Santiago Ezquerro, Juan Antonio Barios, Luis Daniel Lledó, Francisco Javier Badesa and Nicolas Garcia-Aracil</i>	
Sistema de Visión Estereoscópico para el guiado de un Robot Quirúrgico en Operaciones de Cirugía Laparoscópica HALS.....	256
<i>Carlos Castedo Hernández, Rafael Estop Remacha, Eusebio de La Fuente López and Lidia Santos Del Blanco</i>	
Head movement assessment of cerebral palsy users with severe motor disorders when they control a computer thought eye movements.....	264
<i>Alejandro Clemotte, Miguel A. Velasco and Eduardo Rocon</i>	
Diseño de un sensor óptico de fuerza para exoesqueletos de mano.....	270
<i>Jorge Diez Pomares, Andrea Blanco Ivorra, José María Catalan Orts, Francisco Javier Badesa Clemente, José María Sabater and Nicolas Garcia Aracil</i>	
POSIBILIDADES DEL USO DE TRAMAS ARTIFICIALES DE IMAGEN MOTORA PARA UN BCI BASADO EN EEG	276
<i>Josep Dinarès-Ferran, Christoph Guger and Jordi Solé-Casals</i>	
EFFECTOS SOBRE LA ERD EN TAREAS DE CONTROL DE EXOESQUELETO DE MANO EMPLEANDO BCI.....	282
<i>Santiago Ezquerro, Juan Antonio Barios, Arturo Bertomeu-Motos, Luisa Lorente, Nuria Requena, Irene Delegido, Francisco Javier Badesa and Nicolas Garcia-Aracil</i>	
Formulación Topológica Adaptada para la Simulación y Control de Exoesqueletos Accionados con Transmisiones Harmonic Drive.....	288
<i>Andres Hidalgo Romero and Eduardo Rocon</i>	

Identificación de contracciones isométricas de la extremidad superior en pacientes con lesión medular incompleta mediante características espectrales de la electromiografía de alta densidad (HD-EMG)	296
<i>Mislav Jordanic, Mónica Rojas-Martínez, Joan Francesc Alonso, Carolina Migliorelli and Miguel Ángel Mañanas</i>	
Diseño de una plataforma para analizar el efecto de la estimulación mecánica aferente en el temblor de pacientes con temblor esencial	302
<i>Julio S. Lora, Roberto López, Jesús González de La Aleja and Eduardo Rocon</i>	
DEFINICIÓN DE UN PROTOCOLO PARA LA MEDIDA PRECISA DEL RANGO CERVICAL EMPLEANDO TECNOLOGÍA INERCIAL	308
<i>Álvaro Martín, Rafael Raya, Cristina Sánchez, Rodrigo Garcia-Carmona, Oscar Ramirez and Abraham Otero</i>	
SISTEMA BRAIN-COMPUTER INTEFACE DE NAVEGACIÓN WEB ORIENTADO A PERSONAS CON GRAVE DISCAPACIDAD.....	313
<i>Víctor Martínez-Cagigal, Javier Gómez-Pilar, Daniel Álvarez, Eduardo Santamaría-Vázquez and Roberto Hornero</i>	
ESTRATEGIAS DE NEUROESTIMULACIÓN TRANSCRANEAL POR CORRIENTE DIRECTA PARA MEJORA COGNITIVA	320
<i>Silvia Moreno Serrano, Mario Ortiz and José María Azorín Poveda</i>	
COMPARATIVA DE ALGORITMOS PARA LA DETECCIÓN ONLINE DE IMAGINACIÓN MOTORA DE LA MARCHA BASADO EN SEÑALES DE EEG	328
<i>Marisol Rodriguez-Ugarte, Irma Nayeli Angulo Sherman, Eduardo Iáñez and Jose M. Azorin</i>	
DETECCIÓN, MEDIANTE UN GUANTE SENSORIZADO, DE MOVIMIENTOS SELECCIONADOS EN UN SISTEMA ROBOTIZADO COLABORATIVO PARA HALS	334
<i>Lidia Santos, José Luis González, Eusebio de La Fuente, Juan Carlos Fraile and Javier Pérez Turiel</i>	
BIOSENSORES PARA CONTROL Y SEGUIMIENTO PATOLOGÍAS REUMATOIDES	340
<i>Amparo Tirado, Raúl Marín, José V Martí, Miguel Belmonte and Pedro Sanz</i>	
Assessment of tremor severity in patients with essential tremor using smartwatches	347
<i>Miguel A. Velasco, Roberto López-Blanco, Juan P. Romero, M. Dolores Del Castillo, J. Ignacio Serrano, Julián Benito-León and Eduardo Rocon</i>	
INTERFAZ CEREBRO-ORDENADOR PARA EL CONTROL DE UNA SILLA DE RUEDAS A TRAVÉS DE DOS PARADIGMAS DE NAVEGACIÓN	353
<i>Fernández-Rodríguez Álvaro, Velasco-Álvarez Francisco and Ricardo Ron-Angevin</i>	
<hr/> Control Inteligente <hr/>	
Aprendizaje por Refuerzo para sistemas lineales discretos con dinámica desconocida: Simulación y Aplicación a un Sistema Electromecánico	360
<i>Henry Diaz, Antonio Sala and Leopoldo Armesto</i>	
Diseño de sistemas de control en cascada clásico y borroso para el seguimiento de trayectorias	368
<i>Javier G. Gonzalez, Rodolfo Haber, Fernando Matia and Marcelino Novo</i>	

ANÁLISIS FORMAL DE LA DINÁMICA DE SISTEMAS NO LINEALES MEDIANTE REDES NEURONALES.....	376
<i>Eloy Irigoyen, Mikel Larrea, A. Javier Barragán, Miguel Ángel Martínez and José Manuel Andújar</i>	
Predicción de la energía renovable proveniente del oleaje en las islas de Fuerteventura y Lanzarote.	384
<i>G.Nicolás Marichal, Deivis Avila, Ángela Hernández, Isidro Padrón and José Ángel Rodríguez</i>	
Aplicación de Redes Neuronales para la Estimación de la Resistencia al Avance en Buques	393
<i>Daniel Marón Blanco and Matilde Santos</i>	
Novel Fuzzy Torque Vectoring Controller for Electric Vehicles with per-wheel Motors	401
<i>Alberto Parra, Martín Dendaluze, Asier Zubizarreta and Joshué Pérez</i>	
REPOSTAJE EN TIERRA DE UN AVIÓN MEDIANTE ALGORITMOS GENÉTICOS .	408
<i>Elías Plaza and Matilde Santos</i>	
VISUALIZACIÓN WEB INTERACTIVA PARA EL ANÁLISIS DEL CHATTER EN LAMINACIÓN EN FRÍO.....	416
<i>Daniel Pérez López, Abel Alberto Cuadrado Vega and Ignacio Díaz Blanco</i>	
BANCADA PARA ANÁLISIS INTELIGENTE DE DATOS EN MONITORIZACIÓN DE SALUD ESTRUCTURAL.....	424
<i>Daniel Pérez López, Diego García Pérez, Ignacio Díaz Blanco and Abel Alberto Cuadrado Vega</i>	
CONTROL DE UN VEHÍCULO CUATRIRROTOR BASADO EN REDES NEURONALES.....	431
<i>Jesus Enrique Sierra and Matilde Santos</i>	
CONTROL PREDICTIVO FUZZY CON APLICACIÓN A LA DEPURACIÓN BIOLÓGICA DE FANGOS ACTIVADOS.....	437
<i>Pedro M. Vallejo Llamas and Pastora Vega Cruz</i>	
<hr/> Educación en Automática <hr/>	
REFLEXIONES SOBRE EL VALOR DOCENTE DE UNA COMPETICION DE DRONES EN LA EDUCACIÓN PARA EL CONTROL.....	445
<i>Ignacio Díaz Blanco, Alvaro Escanciano Urigüen, Antonio Robles Alvarez and Hilario López García</i>	
Uso del Haptic Paddle con aprendizaje basado en proyectos	451
<i>Juan M. Gandarias, Antonio José Muñoz-Ramírez and Jesus Manuel Gomez-De-Gabriel</i>	
REPRESENTACION INTEGRADA DE ACCIONAMIENTOS MECANICOS Y CONTROL DE EJES ORIENTADA A LA COMUNICACIÓN Y DOCENCIA EN MECATRONICA	457
<i>Julio Garrido Campos, David Santos Esterán, Juan Sáez López and José Ignacio Armesto Quiroga</i>	
Construcción y modelado de un prototipo fan & plate para prácticas de control automático	465
<i>Cristina Lampon, Javier Martin, Ramon Costa-Castelló and Muppaneni Lokesh Chowdary</i>	

EDUCACION EN AUTOMATICA E INDUSTRIA 4.0 MEDIANTE LA APLICACIÓN DE TECNOLOGÍAS 3D	471
<i>Jose Ramon Llata, Esther Gonzalez-Sarabia, Carlos Torre-Ferrero and Ramon Sancibrian</i>	
Desarrollo e implementación de un sistema de control en una planta piloto hibrida.....	479
<i>Maria P. Marcos, Cesar de Prada and Jose Luis Pitarch</i>	
LA INFORMÁTICA INDUSTRIAL EN LAS INGENIERÍAS INDUSTRIALES	486
<i>Rogelio Mazaeda, Eusebio de La Fuente López, José Luis González, Eduardo J. Moya de La Torre, Miguel Angel García Blanco, Javier García Ruiz, María Jesús de La Fuente Aparicio, Gregorio Sainz Palmero and Smaranda Cristea</i>	
Ventajas docentes de un flotador magnético para la experimentación de técnicas control ..	495
<i>Eduardo Montijano, Carlos Bernal, Carlos Sagües, Antonio Bono and Jesús Sergio Artal</i>	
PROGRAMACIÓN ATRACTIVA DE PLC	502
<i>Eduardo J. Moya de La Torre, F. Javier García Ruíz, Alfonso Poncela Méndez and Victor Barrio Lángara</i>	
MODERNIZACIÓN DE EQUIPO FEEDBACK MS-150 PARA EL APRENDIZAJE ACTIVO EN INGENIERÍA DE CONTROL	510
<i>Perfecto Reguera Acevedo, Miguel Ángel Prada Medrano, Antonio Morán Álvarez, Juan José Fuertes Martínez, Manuel Domínguez González and Serafín Alonso Castro</i>	
INNOVACIÓN PEDAGÓGICA EN LA FORMACIÓN DEL PERFIL PROFESIONAL PARA EL DESARROLLO DE PROYECTOS DE AUTOMATIZACIÓN INDUSTRIAL A TRAVÉS DE UNA APROXIMACIÓN HOLÍSTICA.	517
<i>Juan Carlos Ríos, Zaneta Babel, Daniel Martínez, José María Paredes, Luis Alonso, Pablo Hernández, Alejandro García, David Álvarez, Jorge Miranda, Constantino Manuel Valdés and Jesús Alonso</i>	
Aprendiendo Simulación de Eventos Discretos con JaamSim	522
<i>Enrique Teruel and Rosario Aragüés</i>	
RED NEURONAL AUTORREGRESIVA NO LINEAL CON ENTRADAS EXÓGENAS PARA LA PREDICCIÓN DEL ELECTROENCEFALOGRAMA FETAL...	528
<i>Rosa M Aguilar, Jesús Torres and Carlos Martín</i>	
ANÁLISIS DEL COEFICIENTE DE TRANSFERENCIA DE MATERIA EN REACTORES RACEWAYS.....	534
<i>Marta Barceló, Jose Luis Guzman, Francisco Gabriel Acién, Ismael Martín and Jorge Antonio Sánchez</i>	
MODELADO DINÁMICO DE UN SISTEMA DE ALMACENAMIENTO DE FRÍO VINCULADO A UN CICLO DE REFRIGERACIÓN	539
<i>Guillermo Bejarano Pellicer, José Joaquín Suffo, Manuel Vargas and Manuel G. Ortega</i>	
Predictor Intervalar basado en hiperplano soporte	547
<i>José Manuel Bravo Caro, Manuel Vasallo Vázquez, Emilian Cojocarú and Teodoro Alamo Cantarero</i>	
Dynamic simulation applied to refinery hydrogen networks	555
<i>Anibal Galan Prado, Cesar De Prada, Gloria Gutierrez, Rafael Gonzalez and Daniel Sarabia</i>	

APROXIMACIÓN DE MODELOS ALGEBRAICOS MEDIANTE ALAMO Y ECOSIMPRO	563
<i>Carlos Gómez Palacín, José Luis Pitarch, Gloria Gutiérrez and Cesar De Prada</i>	
A Causal Model to Analyze Aircraft Collision Avoidance Deadlock Scenarios	569
<i>Miquel Àngel Piera Eroles, Julia de Homdedeu, Maria Del Mar Tous, Thimjo Koca and Marko Radanovic</i>	
ONLINE DECISION SUPPORT FOR AN EVAPORATION NETWORK	575
<i>José Luis Pitarch, Marc Kalliski, Carlos Gómez Palacín, Christian Jasch and Cesar De Prada</i>	
Predicción de la irradiancia a partir de datos de satélite mediante deep learning	582
<i>Javier Pérez, Jorge Segarra-Tamarit, Hector Beltran, Carlos Ariño, José Carlos Alfonso Gil, Aleks Attanasio and Emilio Pérez</i>	
MODELO DINÁMICO ORIENTADO AL TRATAMIENTO Y SEGUIMIENTO DE LA LEUCEMIA MIELOIDE CRÓNICA	589
<i>Gabriel Pérez Rodríguez and Fernando Morilla</i>	
Modelado y optimización de la operación de un sistema de bombeo de múltiples depósitos	596
<i>Roberto Sanchis Llopis and Ignacio Peñarrocha</i>	
DEVELOPMENT OF A GREY MODEL FOR A MEDIUM DENSITY FIBREBOARD DRYER IN ECOSIMPRO	604
<i>Pedro Santos, Jose Luis Pitarch and César de Prada</i>	
DETECCIÓN AUTOMÁTICA DE FALLOS MEDIANTE MONITORIZACIÓN Y OPTIMIZACIÓN DE LAS FECHAS DE LIMPIEZA PARA INSTALACIONES FOTOVOLTAICAS	611
<i>Jorge Segarra-Tamarit, Emilio Pérez, Hector Beltran, Enrique Belenguer and José Luis Gandía</i>	
Modelado de micro-central hidráulica para el diseño de controladores con aplicación en regiones aisladas de Honduras	618
<i>Alejandro Tapia Córdoba, Pablo Millán Gata, Fabio Gómez-Estern Aguilar, Carmelina Ierardi and Álvaro Rodríguez Del Nozal</i>	
FRAMEWORK PARA EL MODELADO DE UN LAGO DE DATOS	626
<i>J.M Torres, R.M. Aguilar, C.A. Martin and S. Diaz</i>	
SIMULADOR CARDIOVASCULAR PARA ENSAYO DE ROBOTS DE NAVEGACION AUTONOMA	633
<i>José Emilio Traver, Juan Francisco Ortega Morán, Ines Tejado, J. Blas Pagador, Fei Sun, Raquel Pérez-Aloe, Blas M. Vinagre and F. Miguel Sánchez Margallo</i>	
PLANIFICACION DE LA PRODUCCION BASADA EN CONTROL PREDICTIVO PARA PLANTAS TERMOSOLARES	641
<i>Manuel Jesús Vasallo Vázquez, José Manuel Bravo Caro, Emilian Cojocarú and Manuel Emilio Gegundez Arias</i>	
Evaluación multicriterio para la optimización de redes de energía	649
<i>Ascensión Zafra Cabeza, Rafael Espinosa, Miguel Àngel Ridao Carlini and Carlos Bordóns Alba</i>	
Percibiendo el entorno en los robots sociales del RoboticsLab	657
<i>Fernando Alonso Martín, Jose Carlos Castillo Montoya, Àlvaro Castro-Gonzalez, Juan José Gamboa, Marcos Maroto Gómez, Sara Marqués Villaroya, Antonio J. Pérez Vidal and Miguel Àngel Salichs</i>	

DISEÑO DE UNA PRÓTESIS DE MANO ADAPTABLE AL CRECIMIENTO	664
<i>Marta Ayats and Raul Suarez</i>	
COOPERATIVISMO BIOINSPIRADO BASADO EN EL COMPORTAMIENTO DE LAS HORMIGAS	672
<i>Brayan Bermudez, Kristel Novoa and Miguel Valbuena</i>	
PROCEDIMIENTO DE DISEÑO DE UN EXOESQUELETO DE MIEMBRO SUPERIOR PARA SOPORTE DE CARGAS	680
<i>Andrea Blanco Ivorra, Jorge Diez Pomares, David Lopez Perez, Francisco Javier Badesa Clemente, Miguel Ignacio Sanchez and Nicolas Garcia Aracil</i>	
Estructura de control en ROS y modos de marcha basados en máquinas de estados de un robot hexápodo	686
<i>Raúl Cebolla Arroyo, Jorge De Leon Rivas and Antonio Barrientos</i>	
USING AN UAV TO GUIDE THE TELEOPERATION OF A MOBILE MANIPULATOR	694
<i>Josep Arnau Claret and Luis Basañez</i>	
Estudio de los patrones de marcha para un robot hexápodo en tareas de búsqueda y rescate	701
<i>Jorge De León Rivas and Antonio Barrientos</i>	
SISTEMA DE INTERACCIÓN VISUAL PARA UN ROBOT SOCIAL	709
<i>Mario Domínguez López, Eduardo Zalama Casanova, Jaime Gómez García-Bermejo and Samuel Marcos Pablos</i>	
Mejora del Comportamiento Proxémico de un Robot Autónomo mediante Motores de Inteligencia Artificial Desarrollados para Plataformas de Videojuegos	717
<i>David Fernández Chaves, Javier Monroy and Javier Gonzalez-Jimenez</i>	
Micrófonos de contacto: una alternativa para sensado táctil en robots sociales	724
<i>Juan José Gamboa, Fernando Alonso Martín, Jose Carlos Castillo, Marcos Maroto Gómez and Miguel A. Salichs</i>	
Clasificación de información táctil para la detección de personas	732
<i>Juan M. Gandarias, Jesús M. Gómez-De-Gabriel and Alfonso García-Cerezo</i>	
Planificación para interceptación de objetivos: Integración del Método Fast Marching y Risk-RRT	738
<i>David Alfredo Garzon Ramos, Mario Andrei Garzon Oviedo and Antonio Barrientos</i>	
ESTABILIZACIÓN DE UNA BOLA SOBRE UN PLANO UTILIZANDO UN ROBOT PARALELO 6-RSS	746
<i>Daniel González, Lluís Ros and Federico Thomas</i>	
TELEOPERACIÓN DE INSTRUMENTOS QUIRÚRGICOS ARTICULADOS	754
<i>Ana Gómez Delgado, Carlos Perez-Del-Pulgar, Antonio Reina Terol and Victor Muñoz Martinez</i>	
CONTROL OF A ROBOTIC ARM FOR TRANSPORTING OBJECTS BASED ON NEURO-FUZZY LEARNING VISUAL INFORMATION	760
<i>Juan Hernández Vicén, Santiago Martínez de La Casa Díaz and Carlos Balaguer</i>	
PLATAFORMA BASADA EN LA INTEGRACIÓN DE MATLAB Y ROS PARA LA DOCENCIA DE ROBÓTICA DE SERVICIO	766
<i>Carlos G. Juan, Jose Maria Vicente, Alvaro Garcia and Jose Maria Sabater-Navarro</i>	

Estimadores de fuerza y movimiento para el control de un robot de rehabilitación de extremidad superior.....	772
<i>Aitziber Mancisidor, Asier Zubizarreta, Itziar Cabanes, Pablo Bengoa and Asier Brull</i>	
Definiendo los elementos que constituyen un robot social portable de bajo coste	780
<i>Marcos Maroto Gómez, José Carlos Castillo, Fernando Alonso-Martín, Juan José Gamboa, Sara Marqués Villarroya and Miguel Ángel Salichs</i>	
Interfaces táctiles para Interacción Humano-Robot	787
<i>Sara Marqués Villarroya, Jose Carlos Castillo Montoya, Fernando Alonso Martín, Marcos Maroto Gómez, Juan José Gamboa and Miguel A. Salichs</i>	
HERRAMIENTAS DE ENTRENAMIENTO Y MONITORIZACIÓN PARA EL DESMINADO HUMANITARIO	793
<i>Hector Montes, Roemi Fernandez, Pablo Gonzalez de Santos and Manuel Armada</i>	
Control a Baja Velocidad de una Rueda con Motor de Accionamiento Directo mediante Ingeniería Basada en Modelos	799
<i>Antonio José Muñoz-Ramírez, Jesús Manuel Luque-Bedmar, Jesus Manuel Gomez-De-Gabriel, Anthony Mandow, Javier Serón and Alfonso Garcia-Cerezo</i>	
SIMULACIÓN DE VEHÍCULOS AUTÓNOMOS USANDO V-REP BAJO ROS	806
<i>Cándido Otero Moreira, Enrique Paz Domonte, Rafael Sanz Dominguez, Joaquín López Fernández, Rafael Barea, Eduardo Romera, Eduardo Molinos, Roberto Arroyo, Luís Miguel Bergasa and Elena López</i>	
Cinemática y prototipado de un manipulador paralelo con centro de rotación remoto para robótica quirúrgica.....	814
<i>Francisco Pastor, Juan M. Gandarias and Jesús M. Gómez-De-Gabriel</i>	
ANÁLISIS DE ESTABILIDAD DE SINGULARIDADES AISLADAS EN ROBOTS PARALELOS MEDIANTE DESARROLLOS DE TAYLOR DE SEGUNDO ORDEN.....	821
<i>Adrián Peidro Vidal, Óscar Reinoso, Arturo Gil, José María Marín and Luis Payá</i>	
INTERFAZ DE CONTROL PARA UN ROBOT MANIPULADOR MEDIANTE REALIDAD VIRTUAL	829
<i>Elena Peña-Tapia, Juan Jesús Roldán, Mario Garzón, Andrés Martín-Barrio and Antonio Barrientos</i>	
Evolución de la robótica social y nuevas tendencias	836
<i>Antonio J. Pérez Vidal, Alvaro Castro-Gonzalez, Fernando Alonso Martín, Jose Carlos Castillo Montoya and Miguel A. Salichs</i>	
DISEÑO MECÁNICO DE UN ASISTENTE ROBÓTICO CAMARÓGRAFO CON APRENDIZAJE COGNITIVO	844
<i>Irene Rivas-Blanco, M Carmen López-Casado, Carlos Pérez-Del-Pulgar, Francisco García-Vacas, Víctor Fernando Muñoz, Enrique Bauzano and Juan Carlos Fraile</i>	
CÁLCULO DE FUERZAS DE CONTACTO PARA PRENSIONES BIMANUALES.....	852
<i>Francisco Abiud Rojas-De-Silva and Raul Suarez</i>	
Modelado del Contexto Geométrico para el Reconocimiento de Objetos.....	860
<i>José Raúl Ruiz Sarmiento, Cipriano Galindo and Javier Gonzalez-Jimenez</i>	
Estimación Probabilística de Áreas de Emisión de Gases con un Robot Móvil Mediante la Integración Temporal de Observaciones de Gas y Viento	868
<i>Carlos Sanchez-Garrido, Javier Monroy and Javier Gonzalez-Jimenez</i>	

MANIPULADOR AÉREO CON BRAZOS ANTROPOMÓRFICOS DE ARTICULACIONES FLEXIBLES	876
<i>Alejandro Suarez, Guillermo Heredia and Anibal Ollero</i>	
EVALUACIÓN DE UN ENTORNO DE TELEOPERACIÓN CON ROS	864
<i>David Vargas Frutos, Juan Carlos Ramos Martínez, José Luis Samper Escudero, Miguel Ángel Sánchez-Urán González and Manuel Ferre Pérez</i>	

Sistemas de Tiempo Real

GENERACIÓN DE CÓDIGO IEC 61131-3 A PARTIR DE DISEÑOS EN GRAFCET....	892
<i>María Luz Alvarez Gutierrez, Isabel Sarachaga Gonzalez, Arantzazu Burgos Fernandez, Nagore Iriondo Urbistazu and Marga Marcos Muñoz</i>	
CONTROL EN TIEMPO REAL Y SUPERVISIÓN DE PROCESOS MEDIANTE SERVIDORES OPC-UA	900
<i>Francisco Blanes Noguera and Andrés Benlloch Faus</i>	
Control de la Ejecución en Sistemas de Criticidad Mixta	906
<i>Alfons Crespo, Patricia Balbastre, Jose Simo and Javier Coronel</i>	
GENERACIÓN AUTOMÁTICA DEL PROYECTO DE AUTOMATIZACIÓN TIA PORTAL PARA MÁQUINAS MODULARES	913
<i>Darío Orive, Aintzane Armentia, Eneko Fernandez and Marga Marcos</i>	
DDS en el desarrollo de sistemas distribuidos heterogéneos con soporte para criticidad mixta	921
<i>Hector Perez and J. Javier Gutiérrez</i>	
ARQUITECTURA DISTRIBUIDA PARA EL CONTROL AUTÓNOMO DE DRONES EN INTERIOR	929
<i>Jose-Luis Poza-Luján, Juan-Luis Posadas-Yaguë, Giovanni-Javier Tipantuña-Topanta, Francisco Abad and Ramón Mollá</i>	
Ingeniería Conducida por Modelos en Sistemas de Automatización Flexibles	935
<i>Rafael Priego, Elisabet Estévez, Darío Orive, Isabel Sarachaga and Marga Marcos</i>	
Estudio e implementación de Middleware para aplicaciones de control distribuido	942
<i>Jose Simo, Jose-Luis Poza-Lujan, Juan-Luis Posadas-Yaguë and Francisco Blanes</i>	

Visión por Computador

Real-Time Image Mosaicking for Mapping and Exploration Purposes	948
<i>Abdulla Al-Kaff, Juan Camilo Soto Triviño, Raúl Sosa San Frutos, Arturo de La Escalera and José María Armingol Moreno</i>	
ALGORITMO DE SLAM UTILIZANDO APARIENCIA GLOBAL DE IMÁGENES OMNIDIRECCIONALES	956
<i>Yerai Berenguer, Luis Payá, Mónica Ballesta, Luis Miguel Jiménez, Sergio Cebollada and Oscar Reinoso</i>	
Medición de Oximetría de Pulso mediante Imagen fotopletismográfica.....	964
<i>Juan-Carlos Cobos-Torres, Jordan Ortega Rodríguez, Pablo J. Alhama Blanco and Mohamed Abderrahim</i>	
Algoritmo de captura de movimiento basado en visión por computador para la teleoperación de robots humanoides.....	970
<i>Juan Miguel Garcia Haro and Santiago Martinez de La Casa</i>	

COMPARACIÓN DE MÉTODOS DE DETECCIÓN DE ROSTROS EN IMÁGENES DIGITALES	976
<i>Natalia García Del Prado, Victor Gonzalez Castro, Enrique Alegre and Eduardo Fidalgo Fernández</i>	
LOCALIZACIÓN DEL PUNTO DE FUGA PARA SISTEMA DE DETECCIÓN DE LÍNEAS DE CARRIL	983
<i>Manuel Ibarra-Arenado, Tardi Tjahjadi, Sandra Robla-Gómez and Juan Pérez-Oria</i>	
Oculus-Crawl, a Software Tool for Building Datasets for Computer Vision Tasks	991
<i>Iván De Paz Centeno, Eduardo Fidalgo Fernández, Enrique Alegre Gutiérrez and Wesam Al Nabki</i>	
Clasificación automática de obstáculos empleando escáner láser y visión por computador ..	999
<i>Aurelio Ponz, Fernando Garcia, David Martin, Arturo de La Escalera and Jose Maria Armingol</i>	
T-SCAN: OBTENCIÓN DE NUBES DE PUNTOS CON COLOR Y TEMPERATURA EN INTERIOR DE EDIFICIOS	1007
<i>Tomás Prado, Blanca Quintana, Samuel A. Prieto and Antonio Adan</i>	
EVALUACIÓN DE MÉTODOS PARA REALIZAR RESÚMENES AUTOMÁTICOS DE VÍDEOS	1015
<i>Pablo Rubio, Eduardo Fidalgo, Enrique Alegre and Víctor González</i>	
SIMULADOR PARA LA CREACIÓN DE MUNDOS VIRTUALES PARA LA ASISTENCIA A PERSONAS CON MOVILIDAD REDUCIDA EN SILLA DE RUEDAS .	1023
<i>Carlos Sánchez Sánchez, María Cidoncha Jiménez, Emiliano Pérez, Ines Tejado and Blas M. Vinagre</i>	
Calibración Extrínseca de un Conjunto de Cámaras RGB-D sobre un Robot Móvil	1031
<i>David Zúñiga-Nöel, Rubén Gómez Ojeda, Francisco-Ángel Moreno and Javier González Jiménez</i>	

Novel Fuzzy Torque Vectoring Controller for Electric Vehicles with per-wheel Motors

Alberto Parra ^a, Martín Dendaluze ^a, Asier Zubizarreta ^b, Joshué Pérez ^a.

^a Tecnia Research & Innovation, Industry and Transport Division, Spain

^b Dept. of Automatics and System Engineering, University of the Basque Country (UPV/EHU)
Faculty of Engineering of Bilbao, Spain

Abstract

The continuous innovation on the electric vehicle area has led to the use of multi-motor powertrain topologies. These powertrains imply new degrees of freedom and better controllability, thus enabling elaborate control solutions for enhanced vehicle dynamics. This allows not only to achieve better vehicle stability, but also greater performance and responsiveness, leading to safer and more satisfying vehicle handling. This work presents a Fuzzy Torque Vectoring Controller for a rear-wheel drive car with independent motors per wheel. The developed design has been validated in a high fidelity vehicle dynamics simulation platform demonstrating its capability to enhance not only curve performance, but also stability.

Keywords: Torque Vectoring (TV), Electric Vehicle (EV), yaw rate, sideslip angle, Fuzzy Logic .

1 INTRODUCTION

The need of reducing global warming, air pollution and oil dependency has motivated not only the implementation of renewable energies, but also other technologies such as electric vehicles [1]. Although these types of vehicles are still not widely established, the sales of vehicles with electrified powertrains (fully-electric as well as hybrids) are increasing, and they have become one of the main research areas in the automotive industry. The integration of electric motors in propulsion systems provide not only better energy efficiency and lower pollution, but also increased controllability, as these motors offer better response time. This enables to achieve enhanced vehicle handling, not only in the longitudinal dynamics, but also in lateral dynamics. The potential of these aspects, together with increased degrees of freedom, are fuelling a notable interest in the field of control engineering.

Electrified propulsion systems offer a wide variety of possible topologies, with a notable diversity of hybrid solutions. Reducing the scope to purely

electric vehicles, as targeted in this paper, the possible topologies can range from a single electric motor with a mechanical differential, to individual motors per wheel. The solutions with individually controllable motors offer the greatest potential for enhancements to the vehicle's dynamic handling. For this purpose, specialized algorithms, such as Torque Vectoring algorithms are used to control the torque on each wheel. These approaches are capable of improving not only the cornering capabilities (such as greater speed, lateral acceleration and overall responsiveness) but also the vehicle stability under certain circumstances.

Several strategies can be used to control the torque distribution in a Torque Vectoring approach, being most of them based on controlling the moment along the vertical axis of the vehicle (yaw moment). For this purpose, three main strategies are used [16]: the first one is based on the distribution of the torque in the rear axle; the second one is using active vehicle roll control systems to vary the lateral load distribution; finally, the third strategy consists in implementing a steering system in both axles. This work focuses on torque distribution strategies, as a rear-wheel drive vehicle has been selected as study case.

The torque distribution approaches have been implemented using a wide variety of control algorithms. Classical PID approaches have been analyzed in [6], where a very detailed comparison is made between two conventional controllers (traditional PID and adaptive PID) and more innovative controllers (sub-optimal Second Order Sliding Mode (SOSM) controller and twisting SOSM controller). The obtained results allow to deduce that no gain scheduling is necessary to achieve good performance. Furthermore, a better tracking in steady state is achieved for the suboptimal sliding mode approach but undesirable oscillations appear in the yaw rate during step maneuvers at high steering amplitudes. In conclusion, predictable behaviour and good frequency response are key characteristics in favour of PID controllers for real vehicle applications.

Other authors have proposed using advanced control approaches such as MPC [17] or integral

sliding mode control [9]. Although these strategies provide good results, the computational cost of these approaches is higher than simpler approaches such as the PID-based ones.

Finally, some authors have proposed to use intelligent approaches, such as Neural Networks [10] or Fuzzy logic systems [11], demonstrating, though several manoeuvres, how torque vectoring controllers based on this last control technique improves vehicle's handling, stability and path-following. In addition, the use of a fuzzy logic controller provides good results at low computational cost in comparison with previous approaches, being a good alternative to the implementation of torque distribution approaches.

Due to this, in this paper a novel Torque Vectoring algorithm based on fuzzy logic is proposed. The proposed approach provides enhanced lateral dynamic performance by reducing the sideslip angle and controlling the yaw moment at the same time. The approach has been validated in a rear-wheel driven vehicle implemented on a high fidelity dynamics simulator.

The rest of the paper is divided as follows. In section 2 the mathematical model for the generation of the reference variable for the developed fuzzy controller is explained. Section 3 describes the followed process for the design of this controller, which will be validated through the platform described in section 4 by comparing the fuzzy controller and a vehicle without this control system. Finally, the section 5 summarizes the most important ideas and future work.

2 YAW RATE REFERENCE GENERATOR

The developed torque distribution control approach is based on the control of the yaw moment of the vehicle, so that an appropriate yaw rate reference is required for proper performance of the controller. This section provides a detailed description of the model used for the yaw rate reference calculation in the controller. It must be noted that this model of reduced complexity is exclusively used for real-time execution inside the controller.

For the calculation of the desired yaw rate reference, the model known as "bicycle model" will be used (see Fig. 1), which provides a good balance between accuracy and computational cost. Some additional simplifications are done for the sake of computational performance: the center of gravity is assumed to be at a height of zero; the variation of the vertical force of each tire will not be taken into account; small slip angles assumption

will be considered, so that $\sin(\beta) = \beta$ and $\cos(\beta) = 1$ (linear region): and the coefficient of lateral stiffness of the tire will be constant, defined by the ratio of the lateral force to the slip angle.

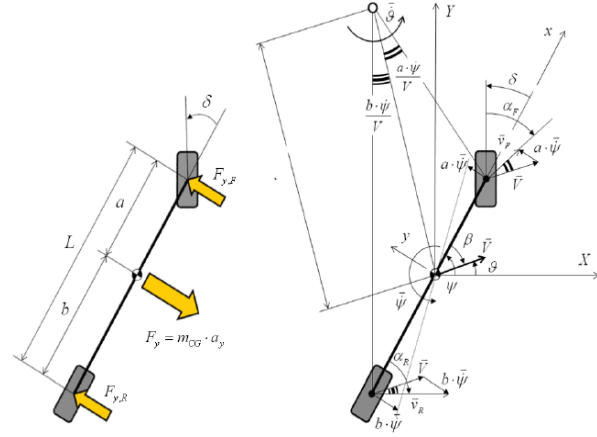


Figure 1: Bicycle model [13].

So, the desired yaw rate is given by the following equation:

$$\dot{\psi} = \frac{V}{L + \frac{m}{L} \left(\frac{b}{C_{\alpha F}} - \frac{a}{C_{\alpha R}} \right) V^2} \delta \quad (1)$$

where a and b are the distance to the centre of gravity of the front and rear axle respectively, δ is the angle of rotation of the front wheels, L is the total distance between axles, m is the total mass of the vehicle located in the center of gravity, V is the vehicle speed and $C_{\alpha F}$ and $C_{\alpha R}$ are the lateral stiffness coefficients of the front and rear wheels, respectively.

However, for safety reasons it will be necessary to limit the value of the yaw rate reference generated. In this case, the limit has been set as follows [6].

$$\left| \dot{\psi}_{ref,max} \right| = \left| \frac{a_y}{V} \right| \quad (2)$$

The yaw moment of the vehicle, for an F_x , is calculated as follows [6],

$$M_{z,Rear} = F_{x,RR} \frac{t_r}{2} + F_{x,RL} \frac{t_r}{2} \quad (3)$$

$$F_{x,RL} = F_{x,RR} = F_{x,R} \quad (4)$$

$$F_{x,R} = \frac{M_{z,Rear}}{t_r} \quad (5)$$

Finally, the maximum moment in the vertical axis of the vehicle that can be generated, taking into

account that the maximum torque that can transmit each tire is 2450 Nm.

$$M_{z,max} = F_{x,R,max} t_r = 2722 \text{ N m} \quad (6)$$

3 FUZZY LOGIC CONTROLLER

In this section a novel fuzzy controller whose objective is to control the yaw moment of the vehicle based on the yaw rate reference described in the previous section is presented. The proposed approach allows to increase and ensure the stability of the vehicle, in addition to improve its handling. Furthermore, the proposed approach, with its Multiple Input Multiple Output (MIMO) structure allows also to reduce the sideslip angle, so that both yaw rate and side slip are controlled, increasing the lateral dynamics performance of the vehicle.

3.1 Fuzzy Logic

Fuzzy logic is an extension of Boolean logic by Lot Zadeh in 1965 [19] based on the mathematical theory of fuzzy sets. By introducing the notion of degree in the verification of a condition, fuzzy logic provides a very valuable flexibility for reasoning [5].

The most common fuzzy logic systems structure is shown in Fig. 2. First a fuzzyfication process must be carried out to transform the input data into fuzzy sets. Second, the data is processed with an inference system, based on the developed rules. Finally, as the real world is continuous, a defuzzification method is necessary in order to convert the result given by the inference system into the exact value to, in our case, ensure a appropriated control.

A very important characteristic of fuzzy logic is that the rules are set in natural language in order to formalize human reasoning. In addition, the whole system is based on the designer’s knowledge.

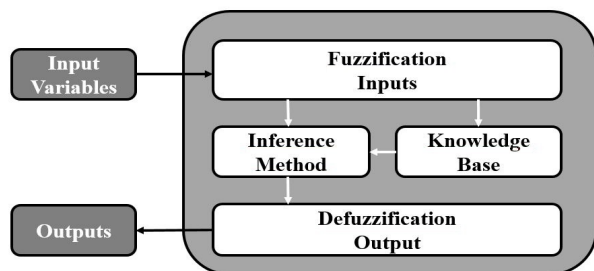


Figure 2: Fuzzy system general scheme

3.2 Fuzzy Controller Design

The proposed Torque Vectoring controller calculates the torque percentage to be subtracted and added to each rear motor (left or right) to perform the torque distribution in the rear axle. This is, if the driver asks for a given torque τ , depending on the yaw rate and side slip angle, the controller calculates a compensation torque percentage τ_c so that $\tau_{left} = \tau + \tau_c$ and $\tau_{right} = \tau - \tau_c$.

For that purpose the controller requires three inputs: the yaw rate error, its derivative and the side slip angle error. The yaw rate error and its derivative are calculated considering the reference detailed in the previous section. The slip angle error is calculated considering that the reference sideslip angle of the vehicle will be zero, in order to reduce the real value and obtain a neutral handling.

One of the most advantages of Fuzzy Logic is the model’s abstraction at the time of tuning. This way, a distribution of 5 membership functions has been chosen for the yaw rate, $e(\psi)$, and lateral slip angle, $e(\beta)$ and three membership functions for the input of the derivative of yaw rate error. The membership functions have been selected as trapezoidal and triangular, as they provide computationally efficient calculations maintaining acceptable smoothness on the response, suitable to be implemented in conventional automotive ECUs. On the other hand, for the output, a more extensive distribution of membership functions has been chosen, nine in this case, aiming to achieve a response as close and smooth as possible.

The structure of the developed fuzzy controller is shown in Fig. 3 with the membership functions.

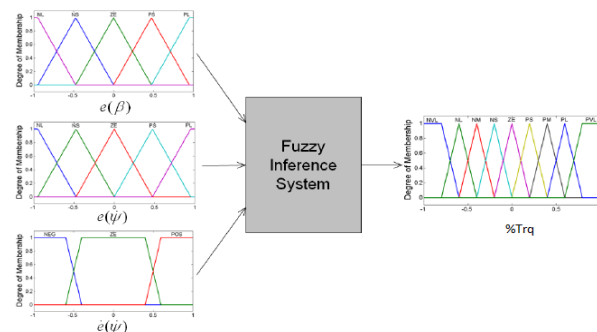


Figure 3: Fuzzy Logic Controller proposed

Subsequently the corresponding rules have been implemented based on the knowledge about the system. Table 1 shows the names and description of the membership functions, while Tables 2-4 show the implemented rules.

The control surfaces obtained are shown in Figs.

Table 1: Membership Functions Names.

Names	Description
NVL	NEGATIVE VERY LARGE
NL	NEGATIVE LARGE
NM	NEGATIVE MEDIUM
NS	NEGATIVE SMALL
ZE	ZERO
PS	POSITIVE SMALL
PM	POSITIVE MEDIUM
PL	POSITIVE LARGE
PVL	POSITIVE VERY LARGE

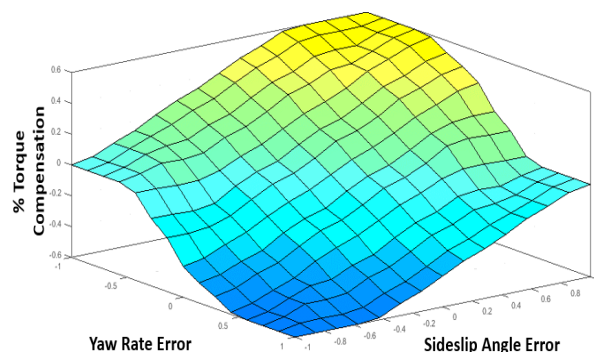


Figure 4: Control surface

Table 2: Rules for negative yaw rate error derivative

$\dot{e}(\psi) < 0$	$e(\psi)$					
		NL	NS	ZE	PS	PL
$e(\beta)$	NL	ZE	NS	NM	NVL	NVL
	NS	ZE	ZE	NS	NL	NVL
	ZE	ZE	ZE	ZE	NS	NL
	PS	PS	PS	ZE	ZE	NS
	PL	PM	PS	PS	ZE	ZE

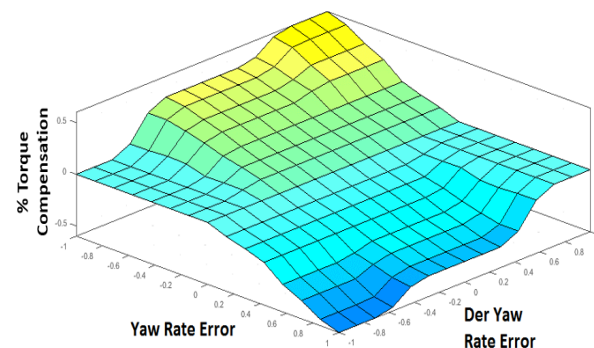


Figure 5: Control surface

Table 3: Rules for zero yaw rate error derivative

$\dot{e}(\psi) = 0$	$e(\psi)$					
		NL	NS	ZE	PS	PL
$e(\beta)$	NL	ZE	ZE	NM	NL	NVL
	NS	PS	ZE	NS	NM	NL
	ZE	PM	PS	ZE	NS	NM
	PS	PL	PM	PS	ZE	NS
	PL	PVL	PL	PM	ZE	ZE

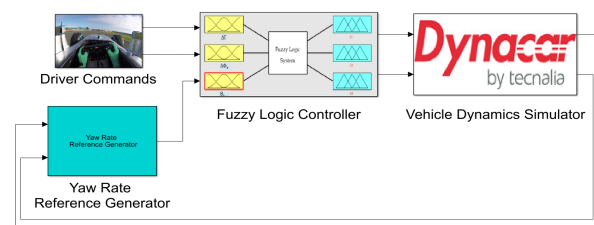


Figure 6: System general scheme

Table 4: Rules for positive yaw rate error derivative

$\dot{e}(\psi) > 0$	$e(\psi)$					
		NL	NS	ZE	PS	PL
$e(\beta)$	NL	ZE	ZE	NS	NS	NM
	NS	PS	ZE	ZE	NS	NS
	ZE	PL	PS	ZE	ZE	ZE
	PS	PVL	PL	PS	ZE	ZE
	PL	PVL	PVL	PM	PS	ZE

4 and 5. The resulting shape of each surface is uniform providing the desired smoothness in the response, in order to achieve better vehicle stability.

4 VALIDATION

For the validation of the proposed algorithm a commercial vehicle dynamics simulation platform, Dynacar, provided by Tecnalia Research & Innovation, has been used [8]. This tool uses an accurate multibody formulation [2], permits the set

up of different MiL and HiL frameworks for accelerated time and real time simulations and has also been involved in race-track validation activities [4] [14]. The multibody model is integrated in the Matlab-Simulink framework as C-Code in an S-Function running at a sampling time of 1ms. Tires are modeled using an implementation of the Pacejka "Magic Formula" model, extensively used by most car manufacturers as an industry standard for vehicle model simulations [13].

The simulated vehicle is a Class E type with two independently controlled electric motors in the rear axle, which are able to provide each a power of 200 kW and 2450 Nm at the wheel (after the reduction gearing).

The following table summarizes the principal char-

acteristics of the vehicle.

Table 5: Vehicle Principal Characteristics.

Mass [kg]	1830
Ix [kgm ²]	928.1
Iy [kgm ²]	2788.5
Iz [kgm ²]	3234.0
Wheelbase [m]	3.05
Front Axis Track [m]	1.6
Rear Axis Track [m]	1.6

The proposed simulation setup is detailed in Fig. 6. In order to test the previously presented control approach, a set of steering and torque commands have been programmed on the simulator, and the performance of the vehicle has been analyzed in two tests: constant curve trajectory and single lane change. Results for each will be analyzed next.

4.1 CONSTANT CURVE TRAJECTORY

In this test, a constant steering input of 45 degrees is applied while the vehicle keeps accelerating 0 km/h to 80 km/h with a constant torque request of 1500 Nm to both wheels in total. The simulation results for both cases (with and without torque vectoring) are shown in Fig. 7 to 10. Fig. 7 shows the trajectory of the vehicle. Fig. 8 shows the motor torques applied in both cases (without torque vectoring, same torque for both). Figs. 9 and 10 show the yaw rate and the lateral acceleration for each case, respectively.

The trajectory shows that the vehicle is able to better stay in the curve as speed increases, meaning that the understeering behaviour of the vehicle, which can be identified with this test, is clearly reduced. This is also reflected in the higher lateral acceleration and yaw-rate in Figs. 9 and 10, which shows higher values and is close to the theoretical values.

4.2 SINGLE LANE CHANGE

The second test consists of an evasive manoeuvre, notably more aggressive -and critical for the stability- than the previous one. A sine wave input of 45 degrees (Fig. 11) is applied while the vehicle is accelerating with a constant torque reference. The plots and legends follow the same logic as for the previous test, besides the steering wheel input in Fig. 11 and sideslip angle in Fig. 15. Fig. 12 shows the trajectory, Fig. 13 the yaw rate and Fig. 14 lateral acceleration.

In this test, there is a major difference in what

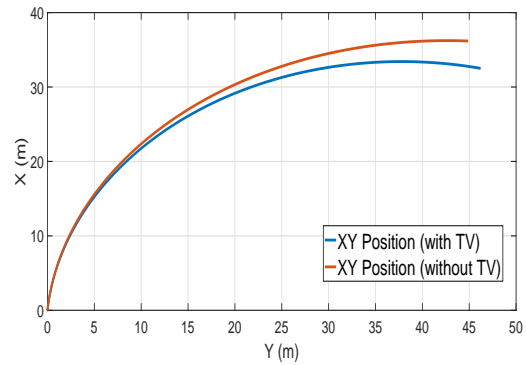


Figure 7: Trajectory

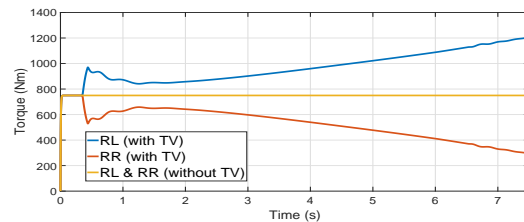


Figure 8: Wheel Torques

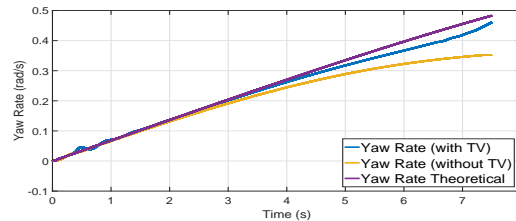


Figure 9: Yaw Rate

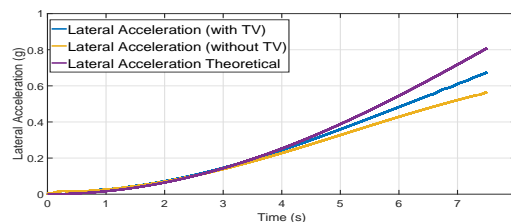


Figure 10: Lateral Acceleration

respects to the trajectory. The vehicle without torque vectoring oversteers as its rear end slides away and the vehicle ends up sliding towards the contrary side. In other words, the vehicle loses stability and it would require the presence of a skilled driver to try to regain the control over the situation. This is also reflected in the lateral acceleration and yaw rate, both reaching excessive magnitudes as the car spins and slides sideways without vectoring (the saturated value of the lateral acceleration can be seen around second 11 in Fig. 13).

This is not the case when the torque vectoring is active. In this case the car is able to follow a neutral trajectory without losing stability, even without a driver closing the loop. This means that the fuzzy control strategy is working correctly. It is able to generate some additional yaw rate and acceleration in the first turn, meaning that it will make a sharper turn, closer to the ideal path, without understeer, similarly to the first test. But in the second part of the manoeuvre, when it needs to turn in the opposite direction, the car tends to reach excessive yaw rate. As the fuzzy torque vectoring controller determines the theoretical yaw-rate internally, it takes action to follow this internal reference avoiding excessive yaw-rate while also minimizing the slip angle.

In other words, the fuzzy torque vectoring controller is able to tackle understeer in the first steering wheel movement, and then control the oversteer in the second steering movement, which otherwise leads to a dangerous stability loss.

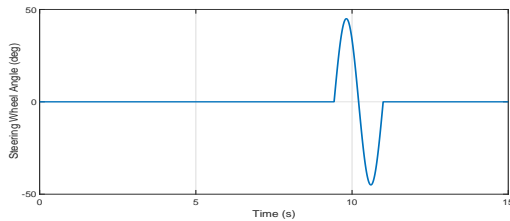


Figure 11: Steering wheel input

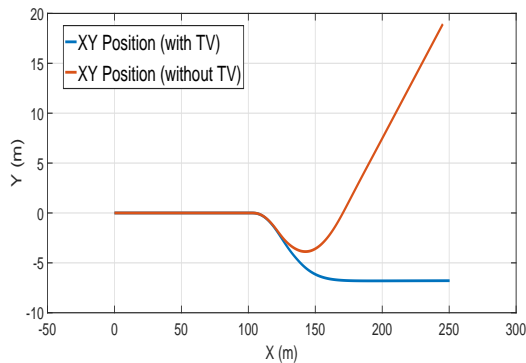


Figure 12: Trajectory

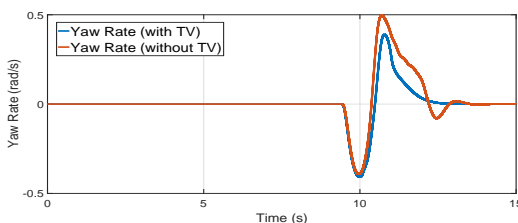


Figure 13: Yaw Rate

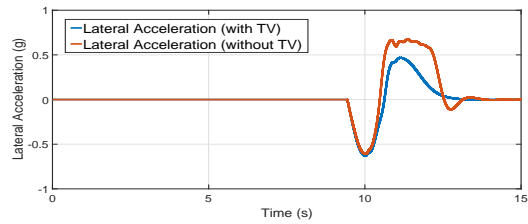


Figure 14: Lateral Acceleration

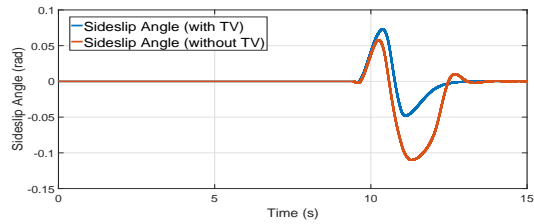


Figure 15: Sideslip angle

5 CONCLUSIONS

This paper has presented a novel Fuzzy Torque Vectoring Controller, for a vehicle with independent rear-wheel motors, with the objectives of increasing cornering performance while also providing additional stability. The results have been notably satisfactory, as it has shown to fulfill these typically contradictory objectives: it was able to increase the cornering forces (reducing understeer), but also was able to control the oversteer in a situation that, in absence of the controller, leads to loss of stability. This is achieved by tracking two inputs of the Fuzzy algorithm -the yaw rate and the side slip angle- while calculating an ideal yaw-rate reference in real-time.

The developed solution has been validated using a highly representative setup including a multi-body vehicle dynamics simulator, which has been exploited to simulate several test procedures.

In conclusion the controllability and degrees of freedom of independent electric motors on vehicles enable enhanced dynamic handling and offer notable research potential for advanced algorithms.

Future work will include implementing an optimized internal set-point generation, while maintaining real-time execution constraints, combining with the implementation of different estimator solutions in real-time to be used as inputs for the torque vectoring controller resulting in a more elaborate algorithm, considering the implementation in new embedded platforms exploiting its computational capacities.

References

- [1] ACEA, (2016) "European Automobile Manufacturers Association - New passenger car registrations by alternative fuel type in the European Union Q4 2015".
- [2] Cuadrado, J., Vilela, D., Iglesias, I., Martín, A., Peña, A., (2013) "A Multibody Model to Assess the Effect of Automotive Motor In-wheel Configuration on Vehicle Stability and Comfort", *ECCOMAS Multibody Dynamics 2013*.
- [3] Dendaluze, M., Allende, M., Pérez, J., Prieto, P., Martín, A., (2016) "Multi Motor Electric Powertrains: Technological Potential and Implementation of a Model Based Approach" *IECON 2016*.
- [4] Dendaluze, M., Iglesias, I., Martín, A., Prieto, P., Peña, A., (2016) "Race-Track testing of a Torque Vectoring Algorithm on a Motor-in-Wheel Car using a Model-Based Methodology with a HiL and Multibody Simulator Setup", *International Conference on Intelligent Transportation Systems*.
- [5] Deroncourt, F. (2013) "Introduction to fuzzy logic" *Massachusetts Institute of Technology*.
- [6] De Novellis, L., Sorniotti, A., Gruber, P., Pennycot, A., (2014) "Comparison of Feedback Control Techniques for Torque-Vectoring Control of Fully Electric Vehicles" *IEEE Transactions on Vehicular Technology*.
- [7] De Novellis, L., Sorniotti, A., Gruber, P., Shead, L., Ivanov, V., Hoepfing, V., (2012) "Torque vectoring for Electric Vehicles with Individually Controlled Motors: State-of-the-Art and Future Developments". *World Electric Vehicle Journal Vol. 5*.
- [8] "Dynacar by Tecnalia." [Online]. Available: <http://www.dynacar.es/en/home.php>.
- [9] Haddoun, A., et al., (2006) "Sliding mode control of EV electric differential system," *Proc. ICEM, Chania, Greece*.
- [10] Haddoun A., M.E.H. Benbouzid, D. Diallo, R. Abdessemed, J. Ghouili, K. Srairi, (2007) "Analysis, Modeling and Neural Network Traction Control of an Electric Vehicle without Differential Gears". *Electric Machines & Drives Conference*.
- [11] Jalali, K., Uchida, T., McPhee, J., and Lambert, S., (2009) "Integrated stability control system for electric vehicles with in-wheel motors using soft computing techniques", *SAE International Journal of Passenger Cars - Electronic and Electrical Systems*.
- [12] Kahveci, H., Ibrahi, H., Ekici, M., (2013) "An electronic differential system using fuzzy logic speed controlled in-wheel brushless DC motors", *Power Engineering Energy and Electrical Drives*.
- [13] Pacejka, H.B. "Tyre and Vehicle Dynamics", BH, 2005.
- [14] Peña, A., Iglesias, I., Valera, J.J., Martín, A., "Development and validation of Dynacar RT software, a new integrated solution for design of electric and hybrid vehicles", *EVS 26 (2012)*.
- [15] Shibahata, Y., Shimada K., Tomari T., (1993) "Improvement of Vehicle Maneuverability by Direct Yaw Moment Control", *Vehicle System Dynamics*, pp. 465-481
- [16] Shimada, K., Shibahata, Y. (1994), "Comparison of Three Active Chassis Control Methods for Stabilizing Yaw Moments", *SAE Technical Paper*.
- [17] Siampis, E., Velenis, E., Longo, S., (2015) "Model Predictive Torque Vectoring Control for Electric Vehicles Near the Limits of Handling" *European Control Conference*.
- [18] Wallentowitz, H., (2005) "Vertical and Lateral Dynamics of Passenger Vehicles", *Automotive Technology II, Institute of Automotive Engineering, Aachen University of Technology, Germany*.
- [19] Zadeh, L. (1965) "Fuzzy Sets" *Information and Control*.