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TABLE OF CONTENTS

SUWS PM21 – 3RD WORKSHOP ON HUMAN FACTORS IN INTELLIGENT VEHICLES

HAND GESTURES TO CONTROL INFOTAINMENT EQUIPMENT IN CARS.....	1
<i>F. Parada-Loira, E. Gonzalez-Agulla, J. Alba-Castro</i>	
STUDYING THE DRIVING PERFORMANCE OF DRIVERS WITH CHILDREN ABOARD BY MEANS OF A FRAMEWORK FOR FLEXIBLE EXPERIMENT CONFIGURATION	7
<i>C. Olaverri-Monreal, J. Goncalves, K. Bengler</i>	
TESTING ADVANCED DRIVER ASSISTANCE SYSTEMS WITH A SERIOUS-GAME-BASED HUMAN FACTORS ANALYSIS SUITE	13
<i>J. Goncalves, R. Rossetti, J. Jacob, J. Goncalves, C. Olaverri-Monreal, A. Coelho, R. Rodrigues</i>	

SUWS PM22 – WORKSHOP ON BENCHMARKING ROAD TERRAIN AND LANE DETECTION ALGORITHMS FOR IN-VEHICLE APPLICATION

COMPREHENSIVE PERFORMANCE ANALYSIS OF ROAD DETECTION ALGORITHMS USING THE COMMON URBAN KITTI-ROAD BENCHMARK.....	19
<i>G. Vitor, A. Victorino, J. Ferreira</i>	
PERFORMANCE EVALUATION FOR CURB DETECTION PROBLEM.....	25
<i>I. Stainvas, Y. Buda</i>	
COLOR-BASED ROAD DETECTION AND ITS EVALUATION ON THE KITTI ROAD BENCHMARK	31
<i>B. Wang, V. Fremont, S. Rodriguez</i>	

MOORAL SESSION 1A1 – VEHICLE ENVIRONMENT PERCEPTION I

WILL THIS CAR CHANGE THE LANE? - TURN SIGNAL RECOGNITION IN THE FREQUENCY DOMAIN.....	37
<i>B. Frohlich, M. Enzweiler, U. Franke</i>	
NON-PARAMETRIC LANE ESTIMATION IN URBAN ENVIRONMENTS.....	43
<i>J. Beck, C. Stiller</i>	
MAP-RELATIVE LOCALIZATION IN LANE-LEVEL MAPS FOR ADAS AND AUTONOMOUS DRIVING	49
<i>R. Matthaei, G. Bagschik, M. Maurer</i>	

MOPOSTER SESSION 1B1 – DRIVER ASSISTANCE SYSTEMS

CAMERA-BASED LANE BORDER DETECTION IN ARBITRARILY STRUCTURED ENVIRONMENTS	56
<i>V. Schomerus, D. Rosebrock, F. Wahl</i>	
DRIVERS' CAR-FOLLOWING CORRELATIVE BEHAVIOR WITH PRECEDING VEHICLES IN MULTILANE DRIVING	64
<i>C. Yu, J. Wang</i>	
IMPROVING TRAFFIC OPERATIONS USING REAL-TIME OPTIMAL LANE SELECTION WITH CONNECTED VEHICLE TECHNOLOGY.....	70
<i>Q. Jin, G. Wu, K. Boriboonsomsin, M. Barth</i>	
A COOPERATIVE ACTIVE BLIND SPOT ASSISTANT AS EXAMPLE FOR NEXT-GEN COOPERATIVE DRIVER ASSISTANCE SYSTEMS (CODAS)	76
<i>O. Sawade, B. Schauffele, J. Buttgerit, I. Radusch</i>	
VEHICLE SAFETY EVALUATION BASED ON DRIVER DROWSINESS AND DISTRACTED AND IMPAIRED DRIVING PERFORMANCE USING EVIDENCE THEORY	82
<i>X. Li, E. Seignez, W. Lu, P. Loonis</i>	
TOWARDS AUTONOMOUS SELF-ASSESSMENT OF DIGITAL MAPS	89
<i>O. Hartmann, M. Gabb, R. Schweiger, K. Dietmayer</i>	

INTEGRATING MOTION AND APPEARANCE CUES FOR OVERTAKING VEHICLE DETECTION	96
<i>A. Ramirez, E. Ohn-Bar, M. Trivedi</i>	
INTELLIGENT DRIVING DIAGNOSIS BASED ON A FUZZY LOGIC APPROACH IN A REAL ENVIRONMENT IMPLEMENTATION.....	102
<i>A. Pinilla, C. Quintero, C. Premachandra</i>	
A LANE CHANGE DETECTION APPROACH USING FEATURE RANKING WITH MAXIMIZED PREDICTIVE POWER.....	108
<i>J. Schlechtriemen, A. Wedel, J. Hillenbrand, G. Breuel, K. Kuhnert</i>	
LOOKING-IN AND LOOKING-OUT VISION FOR URBAN INTELLIGENT ASSISTANCE: ESTIMATION OF DRIVER ATTENTIVE STATE AND DYNAMIC SURROUND FOR SAFE MERGING AND BRAKING.....	115
<i>A. Tawari, S. Sivaraman, M. Trivedi, T. Shannon, M. Tippelhofer</i>	
SEMIVIRTUAL SIMULATIONS FOR THE EVALUATION OF VISION-BASED ADAS	121
<i>M. Zofka, R. Kohlhaas, T. Schamm, M. Zollner</i>	
A SYSTEM DESIGN FOR AUTOMOTIVE AUGMENTED REALITY USING STEREO NIGHT VISION.....	127
<i>A. Hosseini, D. Bacara, M. Lienkamp</i>	
PREDICTION OF DRIVER INTENDED PATH AT INTERSECTIONS.....	134
<i>T. Streubel, K. Hoffmann</i>	
CONCEPT-AWARE ENSEMBLE SYSTEM FOR PEDESTRIAN DETECTION.....	140
<i>H. Lin, K. Kim, K. Choi</i>	
FRAME-RATE VEHICLE DETECTION WITHIN THE ATTENTIONAL VISUAL AREA OF DRIVERS	146
<i>S. Zabihi, S. Beauchemin, E. Medeiros, M. Bauer</i>	
ADAPTIVE TRAFFIC LIGHT PREDICTION VIA KALMAN FILTERING	151
<i>V. Protschky, K. Wiesner, S. Feit</i>	
A METHOD FOR ANALYZING INTERACTION OF DRIVER INTENTION THROUGH VEHICLE BEHAVIOR WHEN MERGING.....	158
<i>K. Yamada, H. Matsuyama, K. Uchida</i>	
ASSESSMENT AND PREDICTION OF OLDER DRIVERS' DRIVING PERFORMANCE	164
<i>Y. Nakano, S. Sano, Y. Yamakage, T. Kojima, C. Kishi, C. Takahashi, Y. Iribe, H. Kawanaka, K. Oguri</i>	
UTILIZING INSTANTANEOUS DRIVING DIRECTION FOR ENHANCING LANE-MARKING DETECTION	170
<i>Y. Seo, R. Rajkumar</i>	
IMPROVED AUTOMOTIVE SELF LEARNING SYSTEM USING HYPOTHESIS TEST TRIGGERED FORGETTING TO ADAPT TO CHANGE POINTS.....	176
<i>R. Heinrichs, M. Fritzsche, I. Radusch</i>	
GENERATING CONTEXTUAL DESCRIPTION FROM DRIVING BEHAVIORAL DATA	183
<i>T. Bando, K. Takenaka, S. Nagasaka, T. Taniguchi</i>	
PRELIMINARY ANALYSIS OF FULL-SCALE DRIVING SIMULATOR DATA FOR UNMASKED SLEEPINESS DETECTION	190
<i>J. Yang, H. Yoon, W. Lee</i>	
LARGE SCALE SEMI-GLOBAL MATCHING ON THE CPU	195
<i>R. Spangenberg, T. Langner, S. Adfeldt, R. Rojas</i>	
ESTIMATION OF TRAFFIC SIGN VISIBILITY CONSIDERING LOCAL AND GLOBAL FEATURES IN A DRIVING ENVIRONMENT.....	202
<i>K. Doman, D. Deguchi, T. Takahashi, Y. Mekada, I. Ide, H. Murase, U. Sakai</i>	
RESULTS OF INITIAL TEST AND EVALUATION OF A DRIVER-ASSISTIVE TRUCK PLATOONING PROTOTYPE	208
<i>R. Bishop, D. Bevil, J. Switkes, L. Park</i>	
DRIVER INTENTION RECOGNITION METHOD BASED ON COMPREHENSIVE LANE- CHANGE ENVIRONMENT ASSESSMENT	214
<i>J. Ding, R. Dang, J. Wang, K. Li</i>	
MULTI-LANE DETECTION BASED ON ACCURATE GEOMETRIC LANE ESTIMATION IN HIGHWAY SCENARIOS	221
<i>S. Kang, S. Lee, J. Hur, S. Seo</i>	
ONTOLOGY-BASED CONTEXT AWARENESS FOR DRIVING ASSISTANCE SYSTEMS.....	227
<i>A. Armand, D. Filliat, J. Ibanez-Guzman</i>	
A MARGIN-BASED APPROACH TO THREAT ASSESSMENT FOR AUTONOMOUS HIGHWAY NAVIGATION.....	234
<i>A. Constantin, J. Park, K. Iagnemma</i>	

DRIVESAFE: AN APP FOR ALERTING INATTENTIVE DRIVERS AND SCORING DRIVING BEHAVIORS	240
<i>L. Bergasa, D. Almeria, J. Almazan, J. Yebes, R. Arroyo</i>	
ADVISORY WARNINGS BASED ON COOPERATIVE PERCEPTION	246
<i>F. Seeliger, G. Weidl, D. Petrich, F. Naujoks, G. Breuel, A. Neukum, K. Dietmayer</i>	
STEREO VISION-BASED DRIVER HEAD POSE ESTIMATION	253
<i>M. Hoffken, E. Tarayan, U. Kreßel, K. Dietmayer</i>	
FROM VIRTUAL TO REALITY, HOW TO PROTOTYPE, TEST AND EVALUATE NEW ADAS: APPLICATION TO AUTOMATIC CAR PARKING	261
<i>D. Gruyer, S. Choi, C. Boussard, B. Andrea-Novel</i>	
A MULTIPLE STACK ARCHITECTURE FOR INTELLIGENT VEHICLES	268
<i>S. Lin, Y. Gu, N. Maxemchuk</i>	
INTEGRITY MONITORING OF NAVIGATION SYSTEMS USING REPETITIVE JOURNEYS	274
<i>C. Zinoune, P. Bonnifait, J. Ibanez-Guzman</i>	
METHODOLOGY FOR IDENTIFYING CAR FOLLOWING EVENTS FROM NATURALISTIC DATA	281
<i>K. Kusano, J. Montgomery, H. Gabler</i>	
A MODEL PREDICTIVE CONTROL ALLOCATION APPROACH TO HYBRID BRAKING OF ELECTRIC VEHICLES	286
<i>C. Satzger, R. Castro, T. Bunte</i>	
DRIVE ANALYSIS USING LANE SEMANTICS FOR DATA REDUCTION IN NATURALISTIC DRIVING STUDIES	293
<i>R. Stazoda, P. Gunaratne, M. Trivedi</i>	
A SUPPORT VECTOR MACHINE APPROACH TO UNINTENTIONAL VEHICLE LANE DEPARTURE PREDICTION	299
<i>A. Albousefi, H. Ying, D. Filev, F. Syed, K. Prakah-Asante, F. Tseng, H. Yang</i>	
AN APPROACH OF HUMAN DRIVING BEHAVIOR CORRECTION BASED ON DYNAMIC WINDOW APPROACH	304
<i>Y. Kang, A. Lima, A. Victorino</i>	
A METHOD FOR REDUCING FALSE WARNINGS IN COLLISION-WARNING SYSTEMS (CWS) DURING TURNING MANEUVERS AT ROAD INTERSECTION	310
<i>M. Pandey, Y. Dalbah</i>	
PEDESTRIAN PATH PREDICTION USING BODY LANGUAGE TRAITS	317
<i>R. Quintero, J. Almeida, D. Llorca, M. Sotelo</i>	

MOORAL SESSION IC1 – IMAGE, RADAR, SIGNAL PROCESSING I

INSTANTANEOUS FULL-MOTION ESTIMATION OF ARBITRARY OBJECTS USING DUAL DOPPLER RADAR	324
<i>D. Kellner, M. Barjenbruch, J. Klappstein, J. Dickmann, K. Dietmayer</i>	
LAPS-II: 6-DOF DAY AND NIGHT VISUAL LOCALISATION WITH PRIOR 3D STRUCTURE FOR AUTONOMOUS ROAD VEHICLES	330
<i>W. Maddern, A. Stewart, P. Newman</i>	
OVERTAKING VEHICLE DETECTION USING A SPATIO-TEMPORAL CRF	338
<i>X. Zhang, P. Jiang, F. Wang</i>	
ROBUST AND CONTINUOUS ESTIMATION OF DRIVER GAZE ZONE BY DYNAMIC ANALYSIS OF MULTIPLE FACE VIDEOS	344
<i>A. Tawari, M. Trivedi</i>	

PAPER MOPOSTER SESSION ID1 – AUTOMATED VEHICLES I

TOWARD HUMAN-LIKE MOTION PLANNING IN URBAN ENVIRONMENTS	350
<i>T. Gu, J. Dolan</i>	
COMPUTATION OF STABLE INTERVAL KALMAN FILTER BOUNDS FOR THEIR USE IN ROBUST STATE ESTIMATION FOR AN UNINHABITED SURFACE VEHICLE WITH BOUNDED INDETERMINATE SYSTEM DYNAMICS	356
<i>A. Motwani, S. Sharma, R. Sutton, P. Culverhouse</i>	
PERFORMANCE CHARACTERISTICS FOR AUTOMATED DRIVING OF LONG HEAVY VEHICLE COMBINATIONS EVALUATED IN MOTION SIMULATOR	362
<i>P. Nilsson, L. Laine, B. Jacobson</i>	

DISCRETE DYNAMIC OPTIMIZATION IN AUTOMATED DRIVING SYSTEMS TO IMPROVE ENERGY EFFICIENCY IN COOPERATIVE NETWORKS	370
<i>P. Themann, R. Krajewski, L. Eckstein</i>	
A SAMPLING-BASED LOCAL TRAJECTORY PLANNER FOR AUTONOMOUS DRIVING ALONG A REFERENCE PATH	376
<i>X. Li, Z. Sun, A. Kurt, Q. Zhu</i>	
EVALUATING HUMAN & COMPUTER FOR EXPRESSWAY LANE CHANGING.....	382
<i>H. Tehrani, K. Muto, K. Yoneda, S. Mita</i>	
COMBINING BEHAVIOR AND SITUATION INFORMATION FOR RELIABLY ESTIMATING MULTIPLE INTENTIONS.....	388
<i>S. Klingelschmitt, M. Platho, H. Groß, V. Willert, J. Eggert</i>	
MOVING OBJECT DETECTION UNDER DYNAMIC BACKGROUND IN 3D RANGE DATA	394
<i>Y. Yang, G. Yan, H. Zhu, M. Fu, M. Wang</i>	
A PREDICTION-BASED REACTIVE DRIVING STRATEGY FOR HIGHLY AUTOMATED DRIVING FUNCTION ON FREEWAYS	400
<i>M. Bahram, A. Wolf, M. Aeberhard, D. Wollherr</i>	
TRAJECTORY PLANNING FOR AUTOMATED PARKING USING MULTI-RESOLUTION STATE ROADMAP CONSIDERING NON-HOLONOMIC CONSTRAINTS.....	407
<i>H. Fuji, J. Xiang, Y. Tazaki, B. Levedahl, T. Suzuki</i>	
LOCALIZATION USING AUTOMOTIVE LASER SCANNERS AND LOCAL PATTERN MATCHING	414
<i>A. Schlichting, C. Brenner</i>	
LANELETS: EFFICIENT MAP REPRESENTATION FOR AUTONOMOUS DRIVING	420
<i>P. Bender, J. Ziegler, C. Stiller</i>	
TOWARDS HIGHLY AUTOMATED DRIVING IN A PARKING GARAGE: GENERAL OBJECT LOCALIZATION AND TRACKING USING AN ENVIRONMENT-EMBEDDED CAMERA SYSTEM.....	426
<i>A. Ibisch, S. Houben, M. Schlipsing, R. Kesten, P. Reimche, F. Schuller, H. Altinger</i>	
A NEW APPROACH FOR AUTONOMOUS VEHICLE NAVIGATION IN URBAN SCENARIOS BASED ON ROADWAY MAGNETS.....	432
<i>G. Zhu, M. Yang, B. Wang, C. Wang</i>	
COLLISION AVOIDANCE CONTROL WITH STEERING USING VELOCITY POTENTIAL FIELD.....	438
<i>N. Shibata, S. Sugiyama, T. Wada</i>	
AUTONOMOUS EMERGENCY STOP SYSTEM	444
<i>S. Kwon, C. Jung, T. Choi, Y. Oh, B. You</i>	
TRAJECTORY PLANNING FOR BERTHA - A LOCAL CONTINUOUS METHOD.....	450
<i>J. Ziegler, P. Bender, T. Dang, C. Stiller</i>	
A BEHAVIORAL PLANNING FRAMEWORK FOR AUTONOMOUS DRIVING.....	458
<i>J. Wei, J. Snider, T. Gu, J. Dolan, b. Litkouhi</i>	
AUTOMATIC PARALLEL PARKING WITH GEOMETRIC CONTINUOUS-CURVATURE PATH PLANNING.....	465
<i>H. Vorobieva, S. Glaser, N. Minoiu-Enache, S. Mammar</i>	
SELF-AUTOMATED PARKING LOTS FOR AUTONOMOUS VEHICLES BASED ON VEHICULAR AD HOC NETWORKING.....	472
<i>M. Ferreira, L. Damas, H. Conceicao, P. d'Orey, R. Fernandes, P. Steenkiste</i>	
A MULTIPLE ATTRIBUTE-BASED DECISION MAKING MODEL FOR AUTONOMOUS VEHICLE IN URBAN ENVIRONMENT.....	480
<i>J. Chen, P. Zhao, H. Liang, T. Mei</i>	
AUTOMATIC PARALLEL PARKING AND PLATOONING TO REDISTRIBUTE ELECTRIC VEHICLES IN A CAR-SHARING APPLICATION	486
<i>M. Marouf, E. Pollard, F. Nashashibi</i>	
VISION-BASED FORWARD COLLISION WARNING SYSTEM DESIGN SUPPORTED BY A FIELD-TEST VERIFICATION PLATFORM	492
<i>B. Ren, W. Deng, C. Tamm, F. Han, Y. Wang</i>	
AUTONOMOUS PARKING FROM A RANDOM DROP POINT	498
<i>S. Kim, W. Liu, K. Marczuk</i>	
IMPROVING AND SIMPLIFYING THE GENERATION OF REFERENCE TRAJECTORIES BY USAGE OF ROAD-ALIGNED COORDINATE SYSTEMS.....	504
<i>J. Hudecek, L. Eckstein</i>	

DYNAMIC TRAJECTORY GENERATION USING CONTINUOUS-CURVATURE ALGORITHMS FOR DOOR TO DOOR ASSISTANCE VEHICLES	510
<i>J. Rastelli, R. Lattarulo, F. Nashashibi</i>	
MPC BASED COLLABORATIVE ADAPTIVE CRUISE CONTROL WITH REAR END COLLISION AVOIDANCE	516
<i>F. Sancar, B. Fidan, J. Huissoon, S. Waslander</i>	
VEHICLE SELF-LOCALIZATION USING OFF-THE-SHELF SENSORS AND A DETAILED MAP	522
<i>M. Lundgren, E. Stenborg, L. Svensson, L. Hammarstad</i>	
SCAN WINDOW BASED PEDESTRIAN RECOGNITION METHODS IMPROVEMENT BY SEARCH SPACE AND SCALE REDUCTION.....	529
<i>R. Brehar, S. Nedeveschi</i>	
A TRAFFIC KNOWLEDGE AIDED VEHICLE MOTION PLANNING ENGINE BASED ON SPACE EXPLORATION GUIDED HEURISTIC SEARCH	535
<i>C. Chen, M. Rickert, A. Knoll</i>	
GRAPH-BASED CONTEXT REPRESENTATION, ENVIRONMENT MODELING AND INFORMATION AGGREGATION FOR AUTOMATED DRIVING	541
<i>S. Ulbrich, T. Nothdurft, M. Maurer, P. Hecker</i>	
A PERFORMANCE TEST FOR A NEW REACTIVE-COOPERATIVE FILTER IN AN EGO- VEHICLE LOCALIZATION APPLICATION.....	548
<i>A. Bacha, D. Gruyer, A. Lambert</i>	
MULTI-SENSOR SELF-LOCALIZATION BASED ON MAXIMALLY STABLE EXTREMAL REGIONS.....	555
<i>H. Deusch, J. Wiest, S. Reuter, D. Nuss, M. Fritzsche, K. Dietmayer</i>	
TESTING AUTONOMOUS DRIVING SYSTEMS AGAINST SENSOR AND ACTUATOR ERROR COMBINATIONS.....	561
<i>P. Minnerup, A. Knoll</i>	
GPS PRECISE POSITIONING WITH PSEUDORANGE EVALUATION USING 3-DIMENSIONAL MAPS.....	567
<i>S. Miura, F. Chen, S. Kamijo</i>	
ARBITRATION FOR BALANCING CONTROL BETWEEN THE DRIVER AND ADAS SYSTEMS IN AN AUTOMATED VEHICLE: SURVEY AND APPROACH	575
<i>P. Morignot, J. Rastelli, F. Nashashibi</i>	
CROWDSOURCED INTERSECTION PARAMETERS: A GENERIC APPROACH FOR EXTRACTION AND CONFIDENCE ESTIMATION	581
<i>C. Ruhhammer, N. Hirsenkorn, F. Klanner, C. Stiller</i>	
LONGITUDINAL AND LATERAL CONTROL FOR AUTONOMOUS GROUND VEHICLES.....	588
<i>C. Filho, D. Wolf, V. Grassi Jr., F. Osorio</i>	
AN APPROACH TO SPEED UP RRT*	594
<i>Y. Shan, B. Li, J. Zhou, Y. Zhang</i>	
REAL-TIME CAPABLE PATH PLANNING FOR ENERGY MANAGEMENT SYSTEMS IN FUTURE VEHICLE ARCHITECTURES	599
<i>J. Brembeck, C. Winter</i>	
EXTENDED COOPERATIVE ADAPTIVE CRUISE CONTROL	605
<i>U. Montanaro, M. Tufo, G. Fiengo, M. Bernardo, A. Salvi, S. Santini</i>	
OPTIMAL FIRING PLANNING ON HIGH EFFICIENT CAR VIA PSO ALGORITHM.....	611
<i>J. Liu, T. Shi, P. Li, H. Ma</i>	

MOORAL SESSION IE1 – DRIVER ASSISTANCE SYSTEMS I

JOINT PROBABILISTIC PEDESTRIAN HEAD AND BODY ORIENTATION ESTIMATION.....	617
<i>F. Flohr, M. Dumitru-Guzu, J. Kooij, D. Gavrila</i>	
ESTIMATION OF THE VEHICLE-PEDESTRIAN ENCOUNTER/CONFLICT RISK ON THE ROAD BASED ON TASI 110-CAR NATURALISTIC DRIVING DATA COLLECTION	623
<i>R. Tian, L. Li, K. Yang, S. Chien, Y. Chen, R. Sherony</i>	
NARROW PASSAGE PATH PLANNING USING FAST MARCHING METHOD AND SUPPORT VECTOR MACHINE	630
<i>Q. Do, S. Mita, K. Yoneda</i>	
AUTOMATIC COLLISION AVOIDANCE DURING PARKING AND MANEUVERING - AN OPTIMAL CONTROL APPROACH.....	636
<i>B. Gutjahr, M. Werling</i>	

TUORAL SESSION IIA1 – AUTOMATED VEHICLES II

RESULTS AND ISSUES OF AN AUTOMATED TRUCK PLATOON WITHIN THE ENERGY ITS PROJECT	642
<i>S. Tsugawa</i>	
PROUD-PUBLIC ROAD URBAN DRIVERLESS TEST: ARCHITECTURE AND RESULTS	648
<i>A. Broggi, P. Cerri, S. Debattisti, M. Laghi, P. Medici, M. Panciroli, A. Prioletti</i>	
USING SCALED DOWN TESTING TO IMPROVE FULL SCALE INTELLIGENT TRANSPORTATION	655
<i>G. Ozbiligin, A. Kurt, U. Ozguner</i>	
VEHICLE LOCALIZATION ENHANCEMENT WITH VANETS	661
<i>A. Peker, T. Acarman, C. Yaman, E. Yuksel</i>	

TUPOSTER SESSION IIB1 – IMAGE, RADAR, LIDAR SIGNAL PROCESSING II

PERFORMANCE OF GLOBAL DESCRIPTORS FOR VELODYNE-BASED URBAN OBJECT RECOGNITION	667
<i>T. Chen, B. Dai, D. Liu, J. Song</i>	
MAP-AIDED LOCALIZATION WITH LATERAL PERCEPTION	674
<i>D. Gruyer, R. Belaroussi, M. Revilloud</i>	
SINGLE CAMERA VEHICLE LOCALIZATION USING SURF SCALE AND DYNAMIC TIME WARPING	681
<i>D. Wong, D. Deguchi, I. Ide, H. Murase</i>	
ROAD TERRAIN DETECTION: AVOIDING COMMON OBSTACLE DETECTION ASSUMPTIONS USING SENSOR FUSION	687
<i>P. Shinzato, D. Wolf, C. Stiller</i>	
MONOCULAR VISUAL LOCALIZATION USING ROAD STRUCTURAL FEATURES	693
<i>Y. Yu, H. Zhao, F. Davoine, J. Cui, H. Zha</i>	
BLOCK-MATCHING STEREO WITH RELAXED FRONTO-PARALLEL ASSUMPTION	700
<i>N. Einecke, J. Eggert</i>	
EVALUATION OF IMAGE PROCESSING ALGORITHMS ON VEHICLE SAFETY SYSTEM BASED ON FREE-VIEWPOINT IMAGE RENDERING	706
<i>A. Oko, T. Sato, H. Kume, T. Machida, N. Yokoya</i>	
FAST ROAD DETECTION AND TRACKING IN AERIAL VIDEOS	712
<i>H. Zhou, H. Kong, J. Alvarez, D. Creighton, S. Nahavandi</i>	
PREDICTING DRIVER MANEUVERS BY LEARNING HOLISTIC FEATURES	719
<i>E. Ohn-Bar, A. Tawari, S. Martin, M. Trivedi</i>	
MOVING VEHICLE DETECTION IN DYNAMIC SCENE USING VECTOR QUANTIZATION	725
<i>L. Gao, W. Liu, R. Niu, Y. Sun, Y. Xin, H. Liang</i>	
ACCURACY ANALYSIS OF SURFACE NORMAL RECONSTRUCTION IN STEREO VISION	730
<i>H. Harms, J. Beck, J. Ziegler, C. Stiller</i>	
NIGHT VISION ANIMAL DETECTION	737
<i>D. Forslund, J. Bjarkefur</i>	
NIGHT-VISION STEREO GRID MAPPING FOR DIGITAL MAP LOCALIZATION	743
<i>F. Schule, M. Kramer, R. Schweiger, K. Kuhnert, K. Dietmayer</i>	
TRAFFIC LIGHTS DETECTION AND STATE ESTIMATION USING HIDDEN MARKOV MODELS	750
<i>A. Gomez, F. Alencar, P. Prado, F. Osorio, D. Wolf</i>	
DIRD IS AN ILLUMINATION ROBUST DESCRIPTOR	756
<i>H. Lategahn, J. Beck, C. Stiller</i>	
A SIFT-BASED MEAN SHIFT ALGORITHM FOR MOVING VEHICLE TRACKING	762
<i>W. Liang, X. Xie, J. Wang, Y. Zhang, J. Hu</i>	
SUPERVISED LEARNING AND EVALUATION OF KITTIS' CARS DETECTOR WITH DPM	768
<i>J. Yebes, L. Bergasa, R. Arroyo, A. Lazaro</i>	
OBJECT PERCEPTION FOR INTELLIGENT VEHICLE APPLICATIONS: A MULTI-SENSOR FUSION APPROACH	774
<i>T. Vu, O. Aycard, F. Tango</i>	
A NOVEL METHOD FOR EXTRINSIC PARAMETERS ESTIMATION BETWEEN A SINGLE-LINE SCAN LIDAR AND A CAMERA	781
<i>P. Tulsuk, P. Srestasathiern, M. Ruchanurucks, T. Phatrapornnant, H. Nagahashi</i>	

A NEW OCCUPANCY GRID OF THE DYNAMIC ENVIRONMENT FOR AUTONOMOUS VEHICLES	787
<i>Y. Xin, H. Liang, T. Mei, R. Huang, M. Du, C. Sun, Z. Wang, R. Jiang</i>	
LOCALIZATION BASED ON REGION DESCRIPTORS IN GRID MAPS.....	793
<i>J. Wiest, H. Deusch, D. Nuss, S. Reuter, M. Fritzsche, K. Dietmayer</i>	
UNDERSTANDING HOW CAMERA CONFIGURATION AND ENVIRONMENTAL CONDITIONS AFFECT APPEARANCE-BASED LOCALIZATION.....	800
<i>A. Bansal, H. Badino, D. Huber</i>	
HIGH ACCURATE AFFORDABLE CAR NAVIGATION USING BUILT-IN SENSORY DATA AND IMAGES ACQUIRED FROM A FRONT VIEW CAMERA	808
<i>H. Kim, K. Choi, I. Lee</i>	
TIRE FORCE ESTIMATION FOR A PASSENGER VEHICLE WITH THE UNSCENTED KALMAN FILTER	814
<i>H. Hamann, J. Hedrick, S. Rhode, F. Gauterin</i>	
ACCURATE SEGMENTATION OF MOVING OBJECTS AND THEIR SHADOWS VIA BRIGHTNESS RATIOS AND MOVEMENT PATTERNS*	820
<i>H. Huang, S. Li, K. Tang, R. Li</i>	
VIDEO-BASED AUTOMATIC TRANSIT VEHICLE INGRESS/EGRESS COUNTING USING TRAJECTORY CLUSTERING.....	827
<i>G. Cheng, Y. Huang, A. Mirzaei, B. Buckles, H. Yang</i>	
ROBUST DAZZLING DETECTION IN A NOVEL VISUAL BASED DAZZLING AVOIDANCE SYSTEM.....	833
<i>X. Liu, A. Leu, D. Bacara, M. Hainfellner, A. Graeser</i>	
CAR DETECTION AT NIGHT USING LATENT FILTERS	839
<i>H. Tehrani, T. Kawano, S. Mita</i>	
IMAGE REPRESENTATIONS ON A BUDGET: TRAFFIC SCENE CLASSIFICATION IN A RESTRICTED BANDWIDTH SCENARIO	845
<i>I. Sikiric, K. Brkic, J. Krapac, S. Segvic</i>	
VISION-BASED PEDESTRIAN DETECTION FOR REAR-VIEW CAMERAS	853
<i>S. Silberstein, D. Levi, V. Kogan, R. Gazit</i>	
DETECTING AND POSITIONING OVERTAKING VEHICLES USING 1D OPTICAL FLOW	861
<i>D. Hultqvist, J. Roll, F. Svensson, J. Dahlin, T. Schon</i>	
FUSION OF MAP MATCHING AND TRAFFIC SIGN RECOGNITION	867
<i>A. Peker, O. Tosun, H. Akin, T. Acarman</i>	
VEHICLE CLASSIFICATION ACCURACY OF AVC AND WIM SITES IN OKLAHOMA	873
<i>M. Kalaa, S. Rajab, H. Refai, D. Johnson</i>	
TOWARDS THE INTRINSIC SELF-CALIBRATION OF A VEHICLE-MOUNTED OMNI-DIRECTIONAL RADially SYMMETRIC CAMERA	878
<i>S. Houben</i>	
UNDERSTANDING HEAD AND HAND ACTIVITIES AND COORDINATION IN NATURALISTIC DRIVING VIDEOS	884
<i>S. Martin, E. Ohn-Bar, A. Tawari, M. Trivedi</i>	
DETECTION AND TRACKING APPROACH USING AN AUTOMOTIVE RADAR TO INCREASE ACTIVE PEDESTRIAN SAFETY	890
<i>M. Heuer, A. Al-Hamadi, A. Rain, M. Meinecke</i>	
VEHICLE CLASSIFICATION AND ACCURATE SPEED CALCULATION USING MULTI-ELEMENT PIEZOELECTRIC SENSOR	894
<i>S. Rajab, A. Mayeli, H. Refai</i>	
VISUAL GUARD RAIL DETECTION FOR ADVANCED HIGHWAY ASSISTANCE SYSTEMS	900
<i>T. Scharwachter, M. Schuler, U. Franke</i>	
SPIDER-BASED STIXEL OBJECT SEGMENTATION	906
<i>F. Erbs, A. Witte, T. Scharwachter, R. Mester, U. Franke</i>	
VEHICLE DETECTION FOR AUTONOMOUS PARKING USING A SOFT-CASCADE ADABOOST CLASSIFIER.....	912
<i>A. Broggi, E. Cardarelli, S. Cattani, P. Medici, M. Sabbatelli</i>	

TUORAL SESSION IIC1 – DRIVER ASSISTANCE SYSTEMS II

ONLINE MANEUVER RECOGNITION AND MULTIMODAL TRAJECTORY PREDICTION FOR INTERSECTION ASSISTANCE USING NON-PARAMETRIC REGRESSION	918
<i>Q. Tran, J. Firl</i>	

PREDICTION OF NEXT CONTEXTUAL CHANGING POINT OF DRIVING BEHAVIOR USING UNSUPERVISED BAYESIAN DOUBLE ARTICULATION ANALYZER	924
<i>S. Nagasaka, T. Taniguchi, K. Hitomi, K. Takenaka, T. Bando</i>	
BAYESIAN NONPARAMETRIC MODELING OF DRIVER BEHAVIOR	932
<i>J. Straub, S. Zheng, J. Fisher III</i>	
A LEARNING CONCEPT FOR BEHAVIOR PREDICTION AT INTERSECTIONS	939
<i>R. Graf, H. Deusch, F. Seeliger, M. Fritzsche, K. Dietmayer</i>	

TUPOSTER SESSION IJDT2 – VEHICLE-TO-VEHICLE COMMUNICATIONS AND COOPERATIVE VEHICLE-HIGHWAY SYSTEMS

ON RELIABILITY REQUIREMENT FOR BSM BROADCAST FOR SAFETY APPLICATIONS IN DSRC SYSTEM	946
<i>W. Li, J. Wu, X. Ma, Z. Zhang</i>	
TIME-ANTS: AN INNOVATIVE TEMPORAL AND SPATIAL ANT-BASED VEHICULAR ROUTING MECHANISM	951
<i>R. Doolan, G. Muntean</i>	
ENHANCING CONNECTIVITY FOR SPECTRUM-AGILE VEHICULAR AD HOC NETWORKS IN FADING CHANNELS	957
<i>D. Rawat, S. Shetty</i>	
PERFORMANCE COMPARISON BETWEEN DS-CDMA IVC USING SIC AND CSMA/OFDM IVC UNDER DENSE TRAFFIC SITUATION	963
<i>S. Sakakibara, R. Kusakari, K. Ohno, M. Itami</i>	
TOWARDS A CROSS-LAYER BASED MAC FOR SMOOTH V2V AND V2I COMMUNICATIONS FOR SAFETY APPLICATIONS IN DSRC/WAVE BASED SYSTEMS	969
<i>K. Rahman, K. Tepe</i>	
IMPACT OF PACKAGE DELIVERY RATE ON SAFETY OF HIGHWAY VEHICLE PLATOONS	974
<i>L. Xu, L. Wang, G. Yin, H. Zhang, J. Guo</i>	
A SIMULATION-BASED BENEFIT ANALYSIS OF DEPLOYING CONNECTED VEHICLES USING DEDICATED SHORT RANGE COMMUNICATION	980
<i>E. Paikari, S. Tahmasseby, B. Far</i>	
VEHICLE COLLISION PROBABILITY CALCULATION FOR GENERAL TRAFFIC SCENARIOS UNDER UNCERTAINTY	986
<i>J. Ward, G. Agamennoni, S. Worrall, E. Nebot</i>	
CONNECTIVITY ANALYSIS FOR VEHICULAR AD HOC NETWORK BASED ON THE EXPONENTIAL RANDOM GEOMETRIC GRAPHS	993
<i>Y. Zhang, H. Zhang, W. Sun, C. Pan</i>	
THE ANALYTIC HIERARCHY PROCESS-BASED OPTIMAL FORWARDER SELECTION IN MULTI-HOP BROADCASTING SCHEME FOR VEHICULAR SAFETY	999
<i>D. Ou, Y. Yang, L. Xue, T. Shen, L. Zhang</i>	
SAFETY APPLICATIONS MODELING AND PERFORMANCE OPTIMIZATION IN ROAD VEHICLE COMMUNICATION USING ON/OFF PARETO PROCESS	1005
<i>Z. Bai, H. Zhang, W. Sun, C. Pan</i>	
REDUCING CARBON EMISSIONS BY INTRODUCING ELECTRIC VEHICLE ENHANCED DEDICATED BUS LANES	1011
<i>R. Doolan, G. Muntean</i>	
CONNECTED VEHICLE ENABLED FREEWAY MERGE ASSISTANCE SYSTEM FIELD TEST: PRELIMINARY RESULTS OF DRIVER COMPLIANCE TO ADVISORY	1017
<i>M. Hayat, H. Park, B. Smith</i>	
IMPROVING GPS-BASED VEHICLE POSITIONING FOR INTELLIGENT TRANSPORTATION SYSTEMS	1023
<i>A. Amini, R. Vaghefi, J. Garza, R. Buehrer</i>	
PRIVACY-BY-DECOY: PROTECTING LOCATION PRIVACY AGAINST COLLUSION AND DEANONYMIZATION IN VEHICULAR LOCATION BASED SERVICES	1030
<i>G. Corser, H. Fu, T. Shu, P. D'Errico, W. Ma, S. Leng, Y. Zhu</i>	
VEHICLE TO PEDESTRIAN COMMUNICATIONS FOR PROTECTION OF VULNERABLE ROAD USERS	1037
<i>J. Anaya, P. Merdrignac, O. Shagdar, F. Nashashibi, J. Naranjo</i>	
TOWARDS A COOPERATIVE ITS VEHICLE APPLICATION ORIENTED SECURITY FRAMEWORK	1043
<i>R. Moalla, B. Lonc, H. Labiod, N. Simoni</i>	

CELL PHONE SUBSCRIBERS MOBILITY PREDICTION USING ENHANCED MARKOV CHAIN ALGORITHM	1049
<i>A. Hadachi, O. Batrashev, A. Lind, G. Singer, E. Vinikko</i>	
EXPERIENCES FROM IMPLEMENTING THE ETSI ITS SECURED MESSAGE SERVICE	1055
<i>N. Nowdehi, T. Olovsson</i>	
FUEL-SAVING POTENTIALS OF PLATOONING EVALUATED THROUGH SPARSE HEAVY-DUTY VEHICLE POSITION DATA	1061
<i>K. Liang, J. Martensson, K. Johansson</i>	
DRIVER AND SITUATION-SPECIFIC IMPACT FACTORS FOR THE ENERGY PREDICTION OF EVS BASED ON CROWD-SOURCED SPEED PROFILES	1069
<i>S. Grubwinkler, M. Hirshvogel, M. Lienkamp</i>	
ON-ROAD PHEV POWER MANAGEMENT WITH HIERARCHICAL STRATEGIES IN VEHICULAR NETWORKS	1077
<i>B. Jiang, Y. Fei</i>	
APPROXIMATE DYNAMIC PROGRAMMING METHODS APPLIED TO FAR TRAJECTORY PLANNING IN OPTIMAL CONTROL	1085
<i>H. Wahl, M. Holzappel, F. Gauterin</i>	
ADAPTIVE INTERNAL MODEL CONTROL FOR AIR-FUEL RATIO REGULATION	1091
<i>N. Kahveci, S. Impram, A. Genc</i>	
PERIODICITY BASED CRUISING CONTROL OF PASSENGER CARS FOR OPTIMIZED FUEL CONSUMPTION	1097
<i>S. Li, S. Xu, G. Li, B. Cheng</i>	
LEGENDRE PSEUDOSPECTRAL COMPUTATION OF OPTIMAL SPEED PROFILES FOR VEHICLE ECO-DRIVING SYSTEM	1103
<i>S. Xu, K. Deng, S. Li, B. Cheng</i>	
ENERGY-EFFICIENT TORQUE DISTRIBUTION FOR AXLE-INDIVIDUALLY PROPELLED ELECTRIC VEHICLES	1109
<i>S. Koehler, A. Viehl, O. Bringmann, W. Rosenstiel</i>	
ENERGY SAVINGS BY WIRELESS CONTROL OF SPEED, SCHEDULING AND TRAVEL TIMES FOR HAULING OPERATION	1115
<i>D. Rylander, J. Axelsson, P. Wallin</i>	
EVOLUTION OF OPTIMAL CONTROL FOR ENERGY-EFFICIENT TRANSPORT	1121
<i>A. Gaier, A. Asteroth</i>	
PNEUMATIC TRAIL BASED SLIP ANGLE OBSERVER WITH DUGOFF TIRE MODEL	1127
<i>S. Song, M. Chun, J. Huissoon, S. Waslander</i>	
BLOCK-SPARSE REPRESENTATION CLASSIFICATION BASED GESTURE RECOGNITION APPROACH FOR A ROBOTIC WHEELCHAIR	1133
<i>A. Boyali, N. Hashimoto</i>	
DESIGN OF A NONLINEAR TRAILER STEERING CONTROLLER	1139
<i>G. Nitzsche, K. Robenack, S. Wagner, S. Zipser</i>	
HVAC SYSTEM MODELING FOR RANGE PREDICTION OF ELECTRIC VEHICLES	1145
<i>R. Valentina, A. Viehl, O. Bringmann, W. Rosenstiel</i>	
PASSIVITY ANALYSIS AND DESIGN OF PASSIVITY-BASED CONTROLLERS FOR TRAJECTORY TRACKING AT HIGH SPEED OF AUTONOMOUS VEHICLES	1151
<i>G. Tagne, R. Talj, A. Charara</i>	
DRIVER RESPONSE AT TYRE BLOW-OUT IN HEAVY VEHICLES AND THE IMPORTANCE OF SCRUB RADIUS	1157
<i>K. Tagesson, B. Jacobson, L. Laine</i>	
INTEGRATED DRIVER CO-PILOTE APPROACH FOR VEHICLE LATERAL CONTROL	1163
<i>N. Oufroukh, S. Mammar</i>	
PROBABILISTIC ATTAINABILITY MAPS: EFFICIENTLY PREDICTING DRIVER-SPECIFIC ELECTRIC VEHICLE RANGE	1169
<i>P. Ondruska, I. Posner</i>	
POSE DETECTION IN TRUCK AND TRAILER COMBINATIONS FOR ADVANCED DRIVER ASSISTANCE SYSTEMS	1175
<i>C. Fuchs, S. Eggert, B. Knopp, D. Zobel</i>	
REAL-TIME ESTIMATION OF THE DISTRIBUTION OF BRAKE RESPONSE TIMES FOR AN INDIVIDUAL DRIVER USING VEHICULAR AD HOC NETWORK	1181
<i>A. Rakhshan, H. Pishro-Nik, E. Ray</i>	
ECO-FRIENDLY FREIGHT SIGNAL PRIORITY USING CONNECTED VEHICLE TECHNOLOGY: A MULTI-AGENT SYSTEMS APPROACH	1187
<i>D. Kari, G. Wu, M. Barth</i>	

INTEGRATION OF MICRO-CHP UNITS INTO BEVS-INFLUENCE ON THE OVERALL EFFICIENCY, EMISSIONS AND THE ELECTRIC DRIVING RANGE	1193
<i>S. Baltzer, J. Gissing, P. Jeck, T. Lichius, L. Eckstein</i>	
RATIONAL TRUCK DRIVING AND ITS CORRELATED DRIVING FEATURES IN EXTRA-URBAN AREAS	1199
<i>C. D'Agostino, A. Saidi, G. Scouarnec, L. Chen</i>	

WEORAL SESSION IIIA1 – VEHICLE ENVIRONMENT PERCEPTION II

OCCUPANCY GRID MAP-BASED EXTENDED OBJECT TRACKING	1205
<i>M. Schutz, N. Appenrodt, J. Dickmann, K. Dietmayer</i>	
PROBABILISTIC INFERENCE OF VISIBILITY CONDITIONS BY MEANS OF SENSOR FUSION	1211
<i>M. Gabb, S. Krebs, O. Lohlein, M. Fritzsche</i>	
ROAD CURB DETECTION BASED ON DIFFERENT ELEVATION MAPPING TECHNIQUES	1217
<i>M. Kellner, M. Bouzouraa, U. Hofmann</i>	
FUSION AT DETECTION LEVEL FOR FRONTAL OBJECT PERCEPTION	1225
<i>R. Chavez-Garcia, T. Vu, O. Aycard</i>	

WEPOSTER SESSION IIIB1 – VEHICLE ENVIRONMENT PERCEPTION III

VIDEO BASED LOCALIZATION FOR BERTHA	1231
<i>J. Ziegler, H. Lategahn, M. Schreiber, C. Keller, C. Knoppel, J. Hipp, M. Hauweis, C. Stiller</i>	
TRAVERSABILITY ANALYSIS USING TERRAIN MAPPING AND ONLINE-TRAINED TERRAIN TYPE CLASSIFIER	1239
<i>H. Roncancio, M. Becker, A. Broggi, S. Cattani</i>	
MULTI-DEPTH CROSS-CALIBRATION OF REMOTE EYE GAZE TRACKERS AND STEREOSCOPIC SCENE SYSTEMS	1245
<i>T. Kowsari, S. Beauchemin, M. Bauer, D. Laurendeau, N. Teasdale</i>	
VISIO-SPATIAL ROAD BOUNDARY DETECTION FOR UNMARKED URBAN AND RURAL ROADS	1251
<i>T. Kuhn, J. Fritzsche</i>	
ROBUST CURB DETECTION AND VEHICLE LOCALIZATION IN URBAN ENVIRONMENTS	1257
<i>A. Hata, F. Osorio, D. Wolf</i>	
VISUALIZING DRIVING VIDEO IN TEMPORAL PROFILE	1263
<i>M. Kilicarslan, J. Zheng</i>	
ENVIRONMENT PERCEPTION FOR INNER-CITY DRIVER ASSISTANCE AND HIGHLY-AUTOMATED DRIVING	1270
<i>C. Glaser, T. Michalke, L. Burkle, F. Niewels</i>	
EXTRINSIC CALIBRATION OF A FISHEYE MULTI-CAMERA SETUP USING OVERLAPPING FIELDS OF VIEW	1276
<i>M. Knorr, J. Esparza, W. Niehsen, C. Stiller</i>	
RAS: RECURSIVE AUTOMOTIVE STEREO	1282
<i>S. Schneider, G. Mueller, J. Kallwies, H. Wuensche</i>	
ROBUST GROUND PLANE INDUCED HOMOGRAPHY ESTIMATION FOR WIDE ANGLE FISHEYE CAMERAS	1288
<i>M. Knorr, W. Niehsen, C. Stiller</i>	
DUAL MULTI-TARGETS TRACKING FOR AMBIGUITIES' IDENTIFICATION AND SOLVING	1294
<i>V. Magnier, D. Gruyer</i>	
IMPACT OF REDUCED VISIBILITY FROM FOG ON TRAFFIC SIGN DETECTION	1302
<i>R. Belaroussi, D. Gruyer</i>	
HYBRID SAMPLING BAYESIAN OCCUPANCY FILTER	1307
<i>A. Negre, L. Rummelhard, C. Laugier</i>	
MULTIPLE EXPOSURE IMAGES BASED TRAFFIC LIGHT RECOGNITION	1313
<i>C. Jang, C. Kim, D. Kim, M. Lee, M. Sunwoo</i>	
ROAD GEOMETRY CLASSIFICATION USING ANN	1319
<i>A. Hata, D. Habermann, F. Osorio, D. Wolf</i>	
SENSOR DATA FUSION FOR MULTIPLE CONFIGURATIONS	1325
<i>F. Sandblom, J. Sørstedt</i>	

ON MODELING EGO-MOTION UNCERTAINTY FOR MOVING OBJECT DETECTION FROM A MOBILE PLATFORM	1332
<i>D. Zhou, V. Fremont, B. Quost, B. Wang</i>	
VISUAL ODOMETRY WITH UNSYNCHRONIZED MULTI-CAMERAS SETUP FOR INTELLIGENT VEHICLE APPLICATION	1339
<i>R. Mhiri, P. Vasseur, S. Mousset, R. Boutteau, A. Bensrhair</i>	
LIDAR SCAN FEATURE FOR LOCALIZATION WITH HIGHLY PRECISE 3-D MAP	1345
<i>K. Yoneda, H. Tehrani, T. Ogawa, N. Hukuyama, S. Mita</i>	
A SEMANTIC APPROACH TO SENSOR-INDEPENDENT VEHICLE LOCALIZATION.....	1351
<i>J. Oberlander, S. Klemm, M. Essinger, A. Roennau, T. Schamm, J. Zollner, R. Dillmann</i>	
SCENE CONTEXT IS MORE THAN A BAYESIAN PRIOR: COMPETITIVE VEHICLE DETECTION WITH RESTRICTED DETECTORS	1358
<i>T. Hecht, M. Mohit, E. Sattarov, A. Gepperth</i>	
A MULTI-MODAL SYSTEM FOR ROAD DETECTION AND SEGMENTATION	1365
<i>X. Hu, S. Rodriguez, A. Gepperth</i>	
CONSISTENT ENVIRONMENTAL MODELING BY USE OF OCCUPANCY GRID MAPS, DIGITAL ROAD MAPS, AND MULTI-OBJECT TRACKING	1371
<i>D. Nuss, M. Stuebler, K. Dietmayer</i>	
BIDIRECTIONAL LOOP CLOSURE DETECTION ON PANORAMAS FOR VISUAL NAVIGATION.....	1378
<i>R. Arroyo, P. Alcantarilla, L. Bergasa, J. Yebes, S. Gamez</i>	
THE NEED FOR GNSS POSITION INTEGRITY AND AUTHENTICATION IN ITS: CONCEPTUAL AND PRACTICAL LIMITATIONS IN URBAN CONTEXTS.....	1384
<i>D. Margaria, E. Falletti, T. Acarman</i>	
MULTI-CLASS SEGMENTATION FOR TRAFFIC SCENARIOS AT OVER 50 FPS	1390
<i>A. Costea, S. Nedevschi</i>	
ANALYSIS OF TEMPORAL VEHICLE BEHAVIORS USING BAG OF DYNAMICAL SYSTEMS.....	1396
<i>C. Sannomiya, K. Kurihara, Y. Tanaka, T. Kashiwakura, K. Nawa</i>	
COUPLED DETECTION, ASSOCIATION AND TRACKING FOR TRAFFIC SIGN RECOGNITION	1402
<i>M. Boumediene, J. Lauffenburger, J. Daniel, C. Cudel</i>	
LAYER-BASED SUPERVISED CLASSIFICATION OF MOVING OBJECTS IN OUTDOOR DYNAMIC ENVIRONMENT USING 3D LASER SCANNER	1408
<i>A. Azim, O. Aycard</i>	
DETECTION OF PARKED VEHICLES FROM A RADAR BASED OCCUPANCY GRID.....	1415
<i>R. Dube, M. Hahn, M. Schutz, J. Dickmann, D. Gingras</i>	
EVIDENTIAL DISTRIBUTED DYNAMIC MAP FOR COOPERATIVE PERCEPTION IN VANETS.....	1421
<i>N. Zoghby, V. Cherfaoui, T. Denoeux</i>	
VISUALIZATION OF DRIVING BEHAVIOR USING DEEP SPARSE AUTOENCODER	1427
<i>H. Liu, T. Taniguchi, T. Takano, Y. Tanaka, K. Takenaka, T. Bando</i>	
3DV-AN EMBEDDED, DENSE STEREOVISION-BASED DEPTH MAPPING SYSTEM	1435
<i>G. Camellini, M. Felisa, P. Medici, P. Zani, F. Gregoretti, C. Passerone, R. Passerone</i>	
DEFINITION OF LOCAL INTEGRITY HEAT MAP.....	1441
<i>E. Kaplan, A. Peker, K. Par, T. Acarman</i>	
ANALYSIS OF PEDESTRIAN DYNAMICS FROM A VEHICLE PERSPECTIVE.....	1445
<i>J. Kooij, N. Schneider, D. Gavrila</i>	
PATH ASSIGNMENT TECHNIQUES FOR VEHICLE TRACKING.....	1451
<i>R. Altendorfer, S. Wirkert</i>	
TEMPORAL PREVIEW ESTIMATION FOR DESIGN OF A LOW COST LANE-FOLLOWING SYSTEM USING A FOWARD-FACING MONOCULAR CAMERA	1457
<i>A. Brown, S. Brennan</i>	
A SINGLE ELEMENT PIEZOELECTRIC SENSOR FOR VEHICLE CLASSIFICATION USING THE RATIO OF TRACK WIDTH TO LENGTH	1463
<i>S. Rajab, H. Refai</i>	
Author Index	

Predicting Driver Maneuvers by Learning Holistic Features

Eshed Ohn-Bar, Ashish Tawari, Sujitha Martin, and Mohan M. Trivedi

Abstract—In this work, we propose a framework for the recognition and prediction of driver maneuvers by considering holistic cues. With an array of sensors, driver's head, hand, and foot gestures are being captured in a synchronized manner together with lane, surrounding agents, and vehicle parameters. An emphasis is put on real-time algorithms. The cues are processed and fused using a latent-dynamic discriminative framework. As a case study, driver activity recognition and prediction in overtaking situations is performed using a naturalistic, on-road dataset. A consequence of this work would be in development of more effective driver analysis and assistance systems.

I. INTRODUCTION

On-road driving behavior consists of intricate, multi-dimensional dynamics. It is the outcome of many variables that interact at a certain place and time. This motivates the study in this paper, which pursues a holistic approach using multiple cues in the scene. When fusing the different modalities in a temporal modeling framework, activity recognition and critical situation prediction can be made more effectively. Furthermore, through studying of temporally discriminative cues, we gain insight into the processes that characterize driver behavior.

One important implication of this work is in the development of driver assistance systems. For instance, human-observing cameras can perceive visual scanning and preparatory movements preceding a maneuver, giving a larger margin of time for prevention of a critical situation. Furthermore, a benefit of integrating driver gestures is in the ability to observe driver *intent* for performing a maneuver. Such knowledge can be incorporated into assistive technologies, which in turn may generate a more effective warning system under unintentional maneuvers (e.g. increased lane deviation), while assessing the need for a warning under intentional maneuvers. In this work, driver, vehicle, and environment cues are modeled to produce prediction of activities. In particular, overtaking event prediction will be studied to show the usefulness in the synergistic approach.

Many current safety systems sense the environment in order to produce a warning to the driver. We motivate the usage of additional cues in particular, driver-based cues. In 2012 alone, 33,561 people died in motor vehicle traffic collisions in the United States [1]. A majority of such accidents involved an inappropriate maneuver or a distracted driver. Lateral control maneuvers such as overtaking and lane

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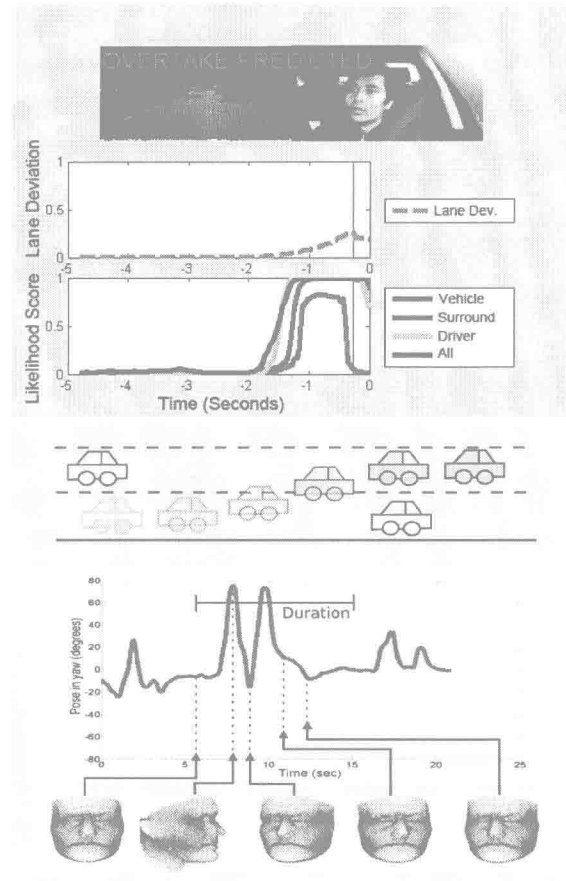


Fig. 1: Different cues are useful for analysis and prediction at different times of the maneuver. Top: An event from our dataset, with lane crossing marked in a vertical red line, and confidence scores from the model. Notice the spike occurring before the event, providing prediction. Bottom: Learning holistic features. For an overtake maneuver, visual scanning and head motion provides predictive value, especially when coupled with surround and vehicle dynamics cues.

changing represent a significant portion of the total accidents each year. Between 2004-2008, 336,000 such crashes occurred in the US [2]. The major contributing factors are driver related (i.e. due to distraction or inappropriate decision making). Therefore, robust vision systems can be employed to detect driver motion patterns, such as head scanning or pre-control actions with foot or hand, and better mitigate critical situations. This work deals with such analysis in a

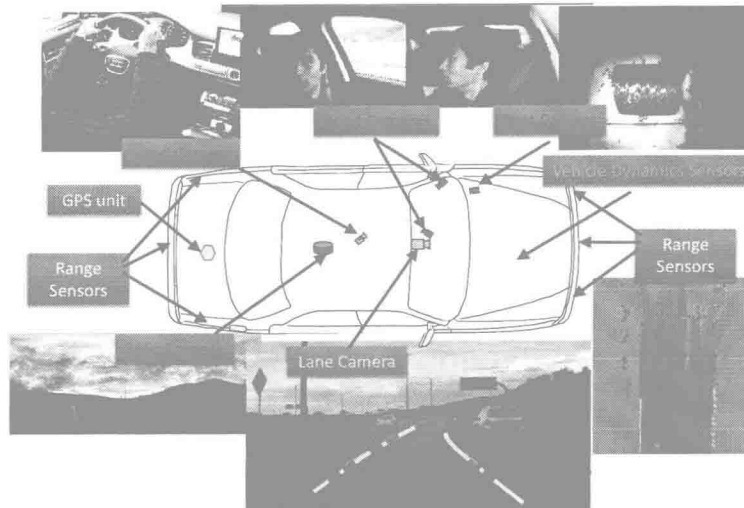


Fig. 2: Safety and driving behavior analysis using a multi-dimensional, holistic framework. The combined system can be used to predict events by a few seconds before they occur, thereby making roads safer and saving lives.

real-time action recognition framework.

First, in Section III we describe the testbed, and Section IV contains the vision algorithms used for signal extraction. The temporal formulation is details in Section V, and experimental analysis on the real-world driving dataset is in Section VII.

II. RELATED RESEARCH

Related research on maneuver recognition and prediction may differ based on cues used, the time-scale of the events of interest, or the type of maneuver studied.

In [3], vehicle dynamics measurements from the CAN-bus are coupled with laser data for preceding vehicles cues to predict driver behavior in a three second window. Yaw and steering-wheel angles were used in [4] for lane departure prediction. In [5] vehicle velocity, steering, and GPS were used to model lane-change behavior and predict collision trajectories. CAN parameters and a Gaussian Mixture Model were used in [6] to study car-following. Vehicle dynamics are used in [7] to identify driver intent at intersections and recognize actions. Vehicle trajectories were used in [8] to model driver intent at intersections using a Probabilistic Finite State Machine. Although methods commonly incorporate ego-vehicle dynamics, others may take on a purely vision approach. In [9], monocular video is used to predict driving behavior in urban environments. A front looking camera was used in [10] to predict future lane change behavior. Recognition of events was done using ego-vehicle dynamics and lane information in [11]. In our work, surrounding agents are modeled by using lidar cues, and a camera is used to extract lane parameters of the scene.

A close effort to our work can be found in [12], where radar, lane, head, and vehicle cues are integrated using a Relevance Vector Machine in order to recognize and

predict lane change maneuvers in a two seconds window. A main difference is in the temporal modeling, as well as the cue representation. For instance, we produce a multi-level representation of the driver's state using head, hand, and foot motion cues. These cues provide additional context information for upcoming maneuvers. Furthermore, the temporal segmentation of actions is done automatically using the model.

Due to the holistic framework, it will be shown that prediction can be accomplished much earlier than in the aforementioned works. The event definition will be explored to highlight the earlier prediction. Generally, the aforementioned work predicts a maneuver after it has began using trajectory forecasting approaches. Nonetheless, we point out that the intent to perform the maneuver existed before the trajectory of the vehicle was altered and can be observed earlier. Within such an early time, a different set of cues may be useful for prediction, these are driver-based.

The closest work to ours of Doshi *et al.* [13] defines a lane change at the maximum lane deviation (i.e. when the vehicle crosses the lane marker). Nonetheless, the driver had the intent to change lanes much earlier, even before any lane deviation occurred. We therefore experiment with an alternate definition (used in [14]), which is at the beginning of the lateral movement. Both definitions will be studied in this work.

III. EXPERIMENTAL SETUP: TESTBED AND DATASET

A 2011 Audi A8 was uniquely instrumented in order to capture the scene holistically: the dynamics of the ego-vehicle, surround agents and road geometry, and the driver's state. Fig. 2 shows a visualization of the sensor array, consisting of vision, radar, lidar, and vehicle CAN data. An on-board PC provides the computational resources. Sensor

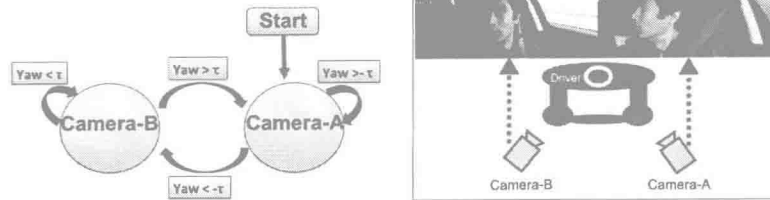


Fig. 3: A two camera system overcomes challenges in head pose estimation and allow for continuous tracking even under large head movements.

data from the radars and lidars are fused to generate a near-panoramic sensing of surrounding objects. These are tracked and associated using a module developed by Audi. UDP/TCP protocols are employed for synchronization of some of the sensors with the main PC. On our dataset, the sensors on average are synchronized up to 22ms.

The array of sensors includes vision-based, non-intrusive driver observing cameras. Two cameras for head pose tracking are used. These are aimed to capture head gestures, such as visual scanning. Two additional cameras provide inputs regarding gestures related to vehicle control. One camera is utilized for hand detection and tracking, and another camera for foot motion analysis.

For sensing the surround, a forward looking camera for lane tracking. Two lidar sensors, one forward and one facing backwards, and two radar sensors on either side of the vehicle. A Ladybug2 360° video camera (composed of an array of 6 individual rectilinear cameras) on top of the vehicle. Combined, these sensors allow for comprehensive and accurate on-line and off-line analysis and annotation.

The sensors are integrated into the vehicle body or placed in non-distracting regions to ensure minimal distraction while driving. Vehicle parameters are recorded into 13 measurements, such as steering angle, throttle and break, and vehicle's yaw rate.

In order to study the feasibility of the proposed framework, a dataset of 54 minutes of video containing 78,018 video frames was used (at 25 frames per second). All results reported employ 2-fold cross validation, with half of the data used for training and the rest for testing. Overall, we use 1000 normal events driving (each defined in a three second window leading to about 75,000 frames) as well as 13 overtaking instances (975 frames) which occurred throughout the video.

IV. HOLISTIC REPRESENTATION OF MANEUVERS

The features used to represent vehicle, surround, and driver, are detailed below. The output from each vision algorithm provides a time-series which is used in the temporal modeling for activity prediction. In this work, the panoramic 360° camera (composed of 6 individual streams) was used for annotation and offline analysis.

A. Head Pose Signal

Real-time, robust head pose is key to early prediction. The head provides a different set of cues (compared to hand and foot) because it is used by drivers for visual scanning and the retrieval of information from the surround. For instance, head motion may precede an overtaking maneuver in order to scan for an available space in the adjacent lane. On the other hand, controlling-gestures are associated with the foot and hand signals. These occur with the driver intention to operate a controller in the vehicle, such as in turning on a lane change indicator.

For capturing the wide motion of the head under such critical situations, we use a spatially distributed set of two cameras around the driver, as in [15].

First, head pose is estimated independently on each camera perspective from some of the least deformable facial landmarks (i.e. eye corners, nose tip), which are detected using supervised descent method [16], and their corresponding points on a 3D mean face model. The system runs at 50Hz. It is important to note that head pose estimation from each camera perspective is with respective camera coordinates. One-time calibration is performed to transform head pose estimation from respective camera coordinates to a common coordinate where a yaw rotation angle equal to, less than and greater than 0° represent the driver looking forward, rightward and leftward, respectively.

A simple camera selection module is used over the wide operational range in the yaw rotation angle, as shown in Fig. 3. In order to handle camera selection and hand-off, we use the yaw angle of the head.

B. Hand Location Signal

Hand gestures are incorporated in order to study preparatory motions before a maneuver is performed. Below, we specify the hand detection and tracking module. Hand detection is a difficult problem in computer vision, due to the hand tendency to occlude itself, deform, and rotate, producing a large variability in its appearance. In [17], motion and appearance cues were studied for hand activity classification in on-road data. As mentioned in [18], hand detection is particularly difficult in the car due to illumination variation. Therefore, we turned to training a hand detector on data from the same vehicle to maximize robustness to background artifacts. We use the fast to compute integral