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PROJECT of the PEGASUS FAMILY

ANALYSIS OF REAL PEDESTRIAN DYNAMICS FOR COORDINATED REAL WORLD SAFETY TESTS WITH AN ADVANCED PEDESTRIAN TARGET AND A MULITDIMENSIONAL TARGET MOVER

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Vehicle manufacturers are continuing to drive forward the development of autonomous vehicles. The preliminary stage along the way are driver assistance systems and emergency braking systems (AEB). These protect vehicle occupants and other road users, such as other vehicles, pedestrians and cyclists. To ensure that emergency braking is only triggered in dangerous situations, sensors and algorithms must detect all road users and assess the probability of collision. To validate the sensor technology and the detection software, vehicle manufacturers are already gathering experience on public roads. Due to the large number of different hazardous situations involving pedestrians and cyclists in urban areas, this approach is not sufficient to ensure the safety of the systems. Therefore, reproducible scenarios with pedestrian and cyclist dummies are needed. In order to reflect the reality of public roads, the dummies should reproduce human behavior and movement as accurately as possible. Pedestrians usually do not cross the street in a straight line or exactly perpendicular to the direction of travel. To imitate this behavior, more complex crossing paths must be possible with the dummies. Furthermore, for an authentic body movement of the pedestrian dummy, the body tilt and the leg and arm movement have to be considered. In order to represent pedestrians realistically in a test environment by dummies, the inclination angles of pedestrians are investigated as a function of speed and trajectory curves. [1]

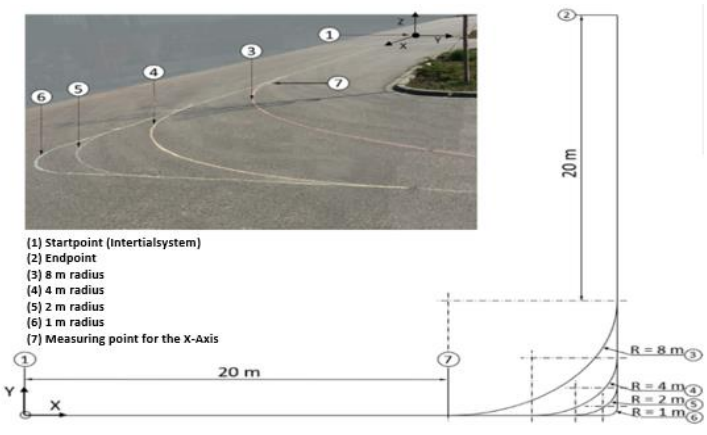

Figure 1: Definition of the study setup

	Walking	Jogging	Running
Speed [m/s]	1,79	3,54	5,65
Acceleration [m/s²]	0,71	1,28	1,9
Decelarion [m/s²]	-0,70	-1,37	-2,06
Pitch Phase 1 [°]	10,11	25,14	39,77
Pitch Phase 2 [°]	2,00	10,33	19,02
Roll [°] R = 8m/4m/ 2m/1m	-	11,56/13,57/ 17,20/18,57	19,89/20,35/ 21,24/21,52

Table 1: Results from the study of the macroscopic movement behavior of humans based on walking mode and radius of the curvature

After the macroscopic determination of the pitch and roll angles of dynamic pedestrians, the microscopic leg movement was investigated. To analyze the complex movement patterns of walking, jogging and running of a pedestrian, the movement sequences of 20 subjects were measured with motion capture sensors. From these data, the step frequency and joint angles for different gaits are determined. The results are used as a benchmark for the validation of pedestrian targets. [2]

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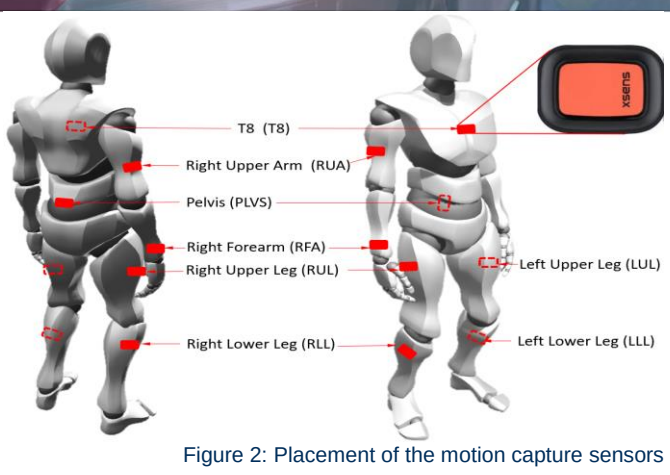

Figure 2: Placement of the motion capture sensors

Figure 3: Biorealistic articulated target for AEB VRU tests ASTERO

In this study, motion capture sensors were used to record the leg movement of dynamic pedestrians. The following information is determined from the measurement data:

- Step frequency for walking, jogging, running
- The hip and knee angles depending on the gait type
- Behavior during velocity changes
- Comparison of the results of the 20 test subjects with current pedestrian targets

	Walking	Jogging	Running
Step frequency [1/min]	113	159	210
Hip joint angles range [°]	-29,45 – 8,65	-40,35 – 6,20	-55,35 – 8,60
Knee joint angles range [°]	-7,50 – 56,90	-1,10 – 74,20	7,40 – 76,90

Table 2: Results from the study of the microscopic movement behavior of the lower extremities

	Walking	Jogging	Running
Step frequency [1/min]	113	156	171
Hip joint angles range [°]	-28,50 – 3,50	-41,70 – 9,20	-46,10 – 5,80
Knee joint angles range [°]	-0,90 – 53,20	-0,60 – 68,40	-6,20 – 71,00

Table 3: Results of measuring the angles of the lower extremities with the MESSRING ASTERO dummy by means of angle sensors

	Walking	Jogging	Running
Step frequency [1/min]	83	105	111
Hip joint angles range [°]	-14,10 – 23,50	-18,60 – 26,10	-20,10 – 25,30
Knee joint angles range [°]	-12,00 – 21,70	-11,70 – 35,70	-13,20 – 33,40

Table 4: Results of measuring the angles of the lower extremities with the 4activePA dummy by means of angle sensors

In addition, sensors were attached to the right upper arm, and the arm movement was measured and analyzed in interaction with the leg movement. For generating synthetic trajectories by an application, the previous study on macroscopic motion behavior of real pedestrians was analyzed and parameters for implementation were defined. Generated trajectories can be transferred to the real world using the multidimensional target mover. [3] Aspects here were:

- Consideration of realistic speed profiles for the gaits "Walking", "Jogging" and "Running".
- Consideration of realistic inclination angles in running direction during acceleration
- Consideration of realistic inclination angles for running in curves

Depending on the selected gait and the resulting target velocities in the respective trajectory segments, the target should correspond with respect to its microscopic motion sequence. Trajectories for test scenarios can be defined based on the previous work packages by attaching straight and curved segments and specifying the gait in each segment section.

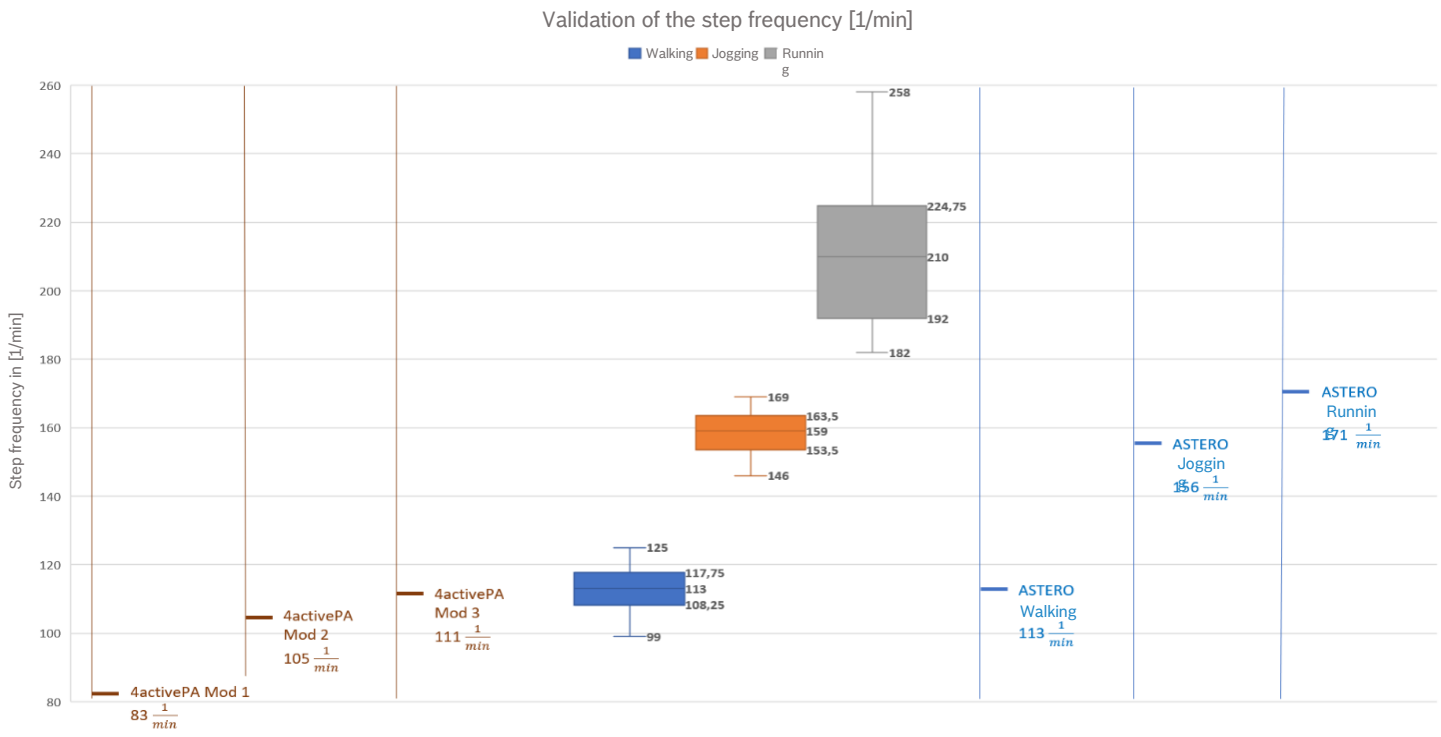

Figure 4: Box diagrams of step frequency of 20 test subjects in comparison with ASTERO and 4activePA

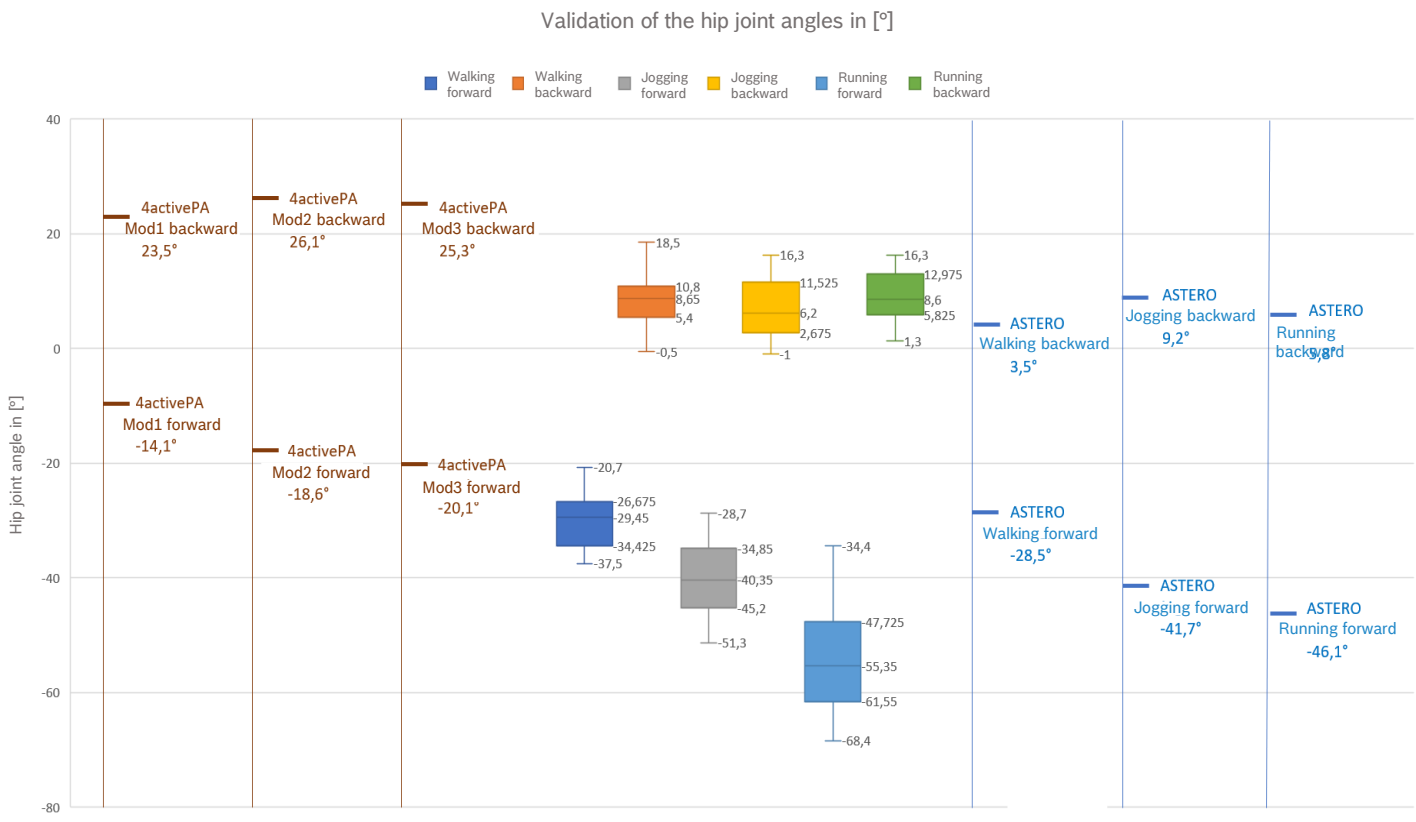

Figure 5: Box diagrams hip joint angles of 20 test subjects in comparison with ASTERO and 4activePA

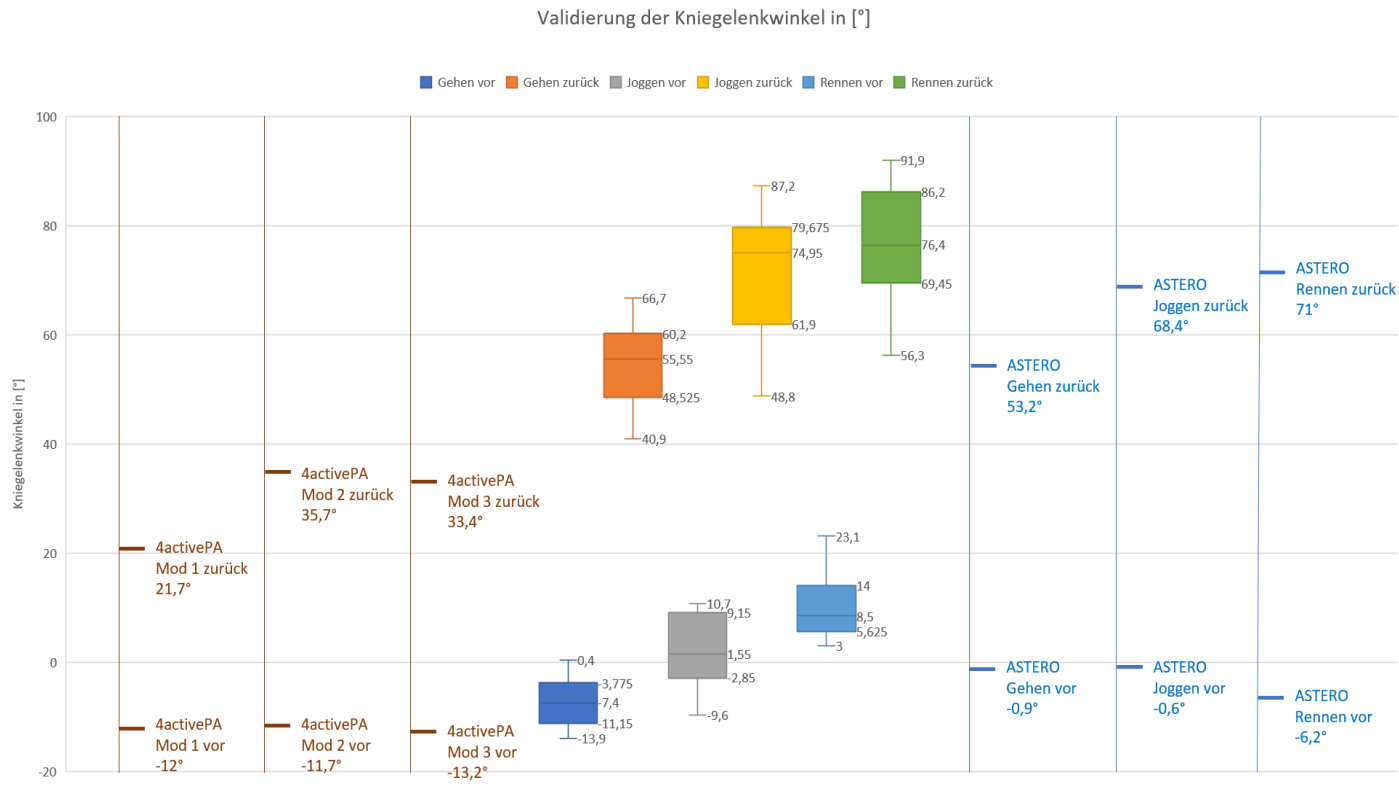

Figure 6: Box diagrams knee joint angles of 20 test subjects in comparison with ASTERO and 4activePA

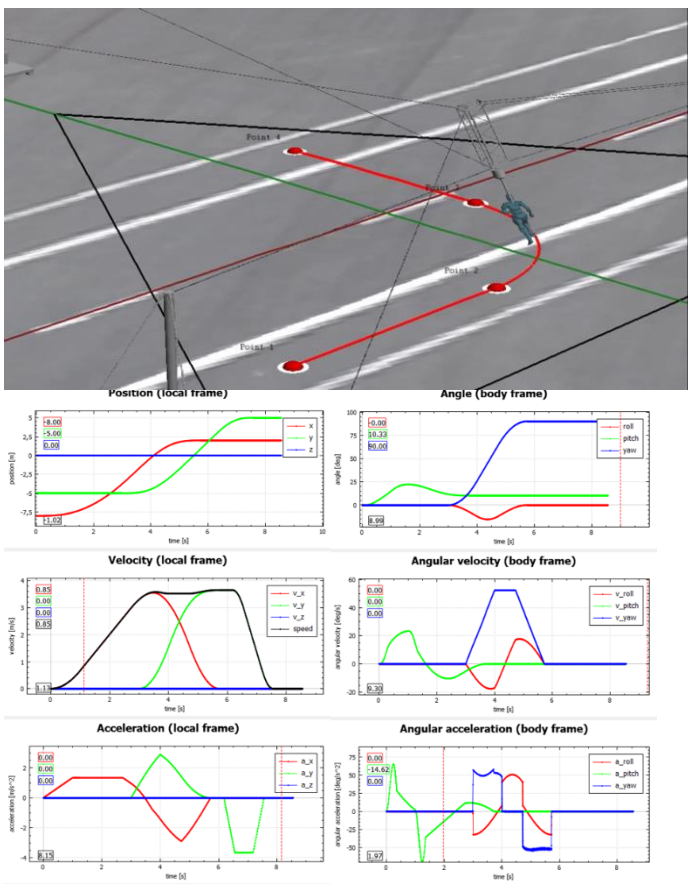

Figure 7: Plots of the dynamic progressions of the visualized trajectory

With these settings and the determined accelerations and velocities from previous studies, temporal velocity curves are generated for the created trajectories.

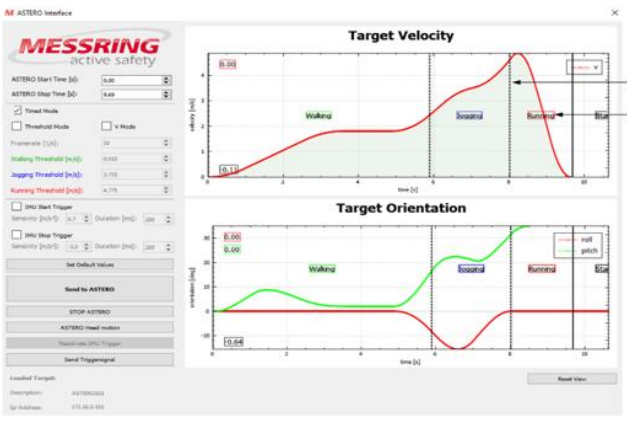

Figure 8: Interface for generating the microscopic motion pattern

On this basis, a method was used to synthetically generate the microscopic leg motion that matches the velocity of the pedestrian test targets. Fig. 8 shows an exemplary implementation for the interface between macroscopically defined motion for the created trajectory and the pedestrian dummy for the generation of the leg motion. The temporal sections of the individual trajectory segments are separated from each other by vertical lines in the described procedure and the corresponding gait is labeled accordingly for each segment. The descripttion of the motion sequence associated with the gait types from previous studies was already considered in the parameterzation for the pedestrian dummy; the joint angle and step frequency parameters used for the particular gait types were generated from the results of previous work packages and transferred to the pedestrian target. For the test sequence, the transit times associated with the respective segment are also calculated and transferred to the pedestrian test target together with the gait type. When the test is triggered, the macroscopic and microscopic motion sequence starts time-controlled. Due to the motion information obtained, the start time and gait type for each section is defined. [4]

Figure 9: Multidimensional target mover at Daimler Testcenter Immendingen © *2003-2020 Mercedes-Benz AG*

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