Trajectory Prediction and Path Planning of Humanoid Robots in Unknown and Unstructured environment - Cognitive Aspects of Autonomous Locomotion

Keywords – Humanoid robots, autonomous locomotion, trajectory prediction, parth planning, simultaneous localization and maping, cognitive behavior

The research is addressed to the synthesis of an intelligent autonomous locomotion (artificial gait) of biped (humanoid) robots in unknown and unstructured dynamic environments through perception, learning, environment understanding and spatial reasoning. Focusing the research activities to the embodied cognition, this research contributes to the extension of the intelligent robot behavior through dynamic environment understanding, simultaneous localization and mapping, trajectory prediction and path planning, obstacle avoidance, collision avoidance and scenario-based behavior.

Main objectives of the research concern with building of advanced bio-inspired methodologies of perception, understanding, artificial reasoning and autonomous locomotion in unknown environment with humanoid robots. In that sense, the following facts are assumed. Healthy adults move free, quite autonomously in the 3D-world based on their natural perception (visual, sound, vestibular, scent, etc.), knowledge, experience and skill of logical thinking (reasoning). Infants learn skill of navigation and walking in free space through training (trial and error) and natural instinct. In such process of learning they have only their perception and still entirely non-developed intellectual capabilities. They have no significant experience about terrain topology and dimensional relationships between existing objects in surrounding. In spite of that, infants learn quickly by exploration of the space around themselves. In that, visual feedback, i.e. object-based localization is the crucial natural principle enables humans to guide themselves in the unknown environment. In the space, people determine their relative position and direction of motion with respect to the characteristic, well-displayed object(s) as it is shown in Fig. 1. A lantern (light) represents landmark object in this example shown in Fig. 1. Under the notion landmark object or marker, a real object or figure/shape that dominates in certain a way comparing with other objects/shapes in surrounding by its dimension (large, high, width), brightness, color, etc, are assumed. Conventionally, biped robots are equipped by a stereo-vision system (two cameras). The role of cameras is to identify the relative position d and direction of motion (azimuth) β of biped robot with respect to the chosen landmark object (Fig. 2) with a satisfactory accuracy.

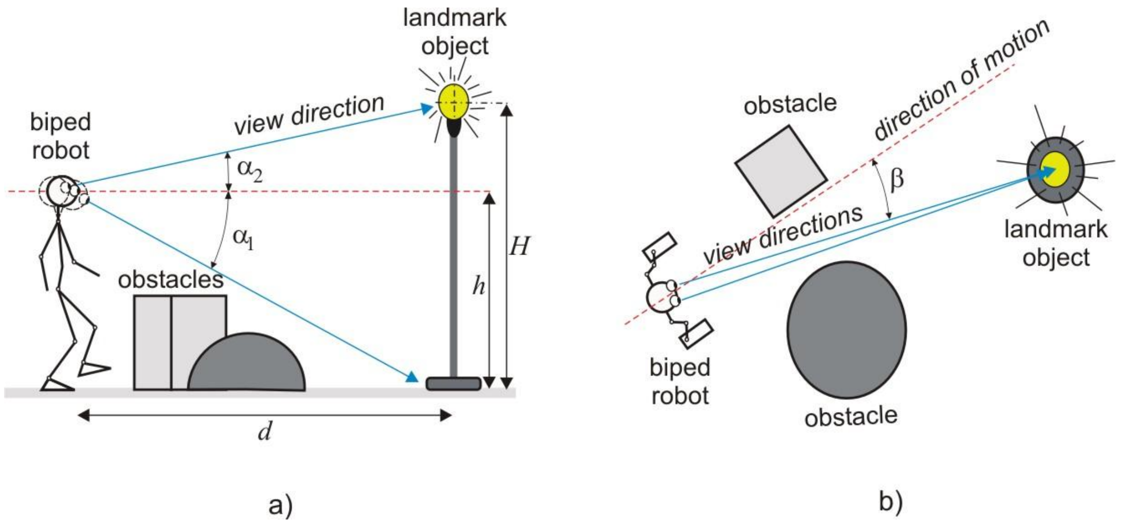

Figure 1: Bio-inspired localization of a biped robot: a) relative position and dimensions of surrounding objects, b) azimuth angle towards landmark/target object

The choice of the appropriate marker can be made by training an appropriate artificial connectionist structure (a kind of robot brain/memory) built into the robot's high-level control block. Such network structure is trained off-line to recognize the potential landmark objects, i.e. bright, large, high or colored objects that can be potentially well displayed in the unknown scene (depending on indoor or outdoor applications). An arbitrary indoor scene with a biped robot and obstacles are presented in Fig. 1 in two geometry perspectives - side view and top view. Elevation angles of robot eyes/cameras α_1 and α_2 as well as their attitude h are known (measurable). Robot relative position (distance d) is calculated from the relation $d = h / tg(\alpha_1)$ while the height of the object H can be estimated as $H = h + d \cdot tg(\alpha_2)$. Elevation angles α_1 and α_2 can be obtained from the encoder sensor situated in the neck's pitch joint (Fig. 1) or by measuring the tilt pitch angles of cameras as alternative. Azimuth angle, i.e. angle of direction of motion β is estimated by measuring the relative yaw angle of the neck joint as it is shown in Fig. 1. In such a way, a bio-inspired, simple way of robot *SLAM* (Simultaneous Localization And Mapping) and advanced navigation algorithms will be realized. Determined geometry values α_1, α_2, β, d and H identified by corresponding robot acquisition system are forwarded to the high-level (cognitive) control block of a humanoid robot. Beside the visual feedback information ensured by a pair of video cameras (see Fig. 1b), additional information about existence of obstacles is necessary for obstacle avoidance as well as robot trajectory prediction. The accurate distance(s) of the obstacle(s) inside the circle of $r \sim 1.00 - 1.50 \quad [m]$ can be obtained from the appropriate distance sensors. For that purpose Ultrasonic Range Finder (USRF) or laser scanner receiver (LSR) are commonly used in robotic practice depending on desired accuracy, assembling possibilities to the mechanical structure, price, etc. By implementation of the USRF sensors it is possible to detect existence of the obstacles in a robot collision zone as well as direction of motion of possible mobile obstacles/objects in the robot surrounding. By numerical differentiation of the identified/measured distance(s) between the robot and moving object(s) it is possible to estimate its/their speed(s) and acceleration(s) of motion. These are important indicators to be used for making the strategy of collision avoidance.

During motion in unknown environment people comes in zones close to the obstacles (Fig. 1b). In order to avoid obstacles they make appropriate actions: change the course, i.e. direction of motion ε, vary the forward velocity v, step length s, step period T, foot lifting height h_f, etc. Mentioned variables ε, v, s, T, h_f represents the *gait parameters* G_p. These parameters represent output variables of the new cognitive block for robot trajectory prediction and planning (generation of feet cycloids) that will be integrated in the robot's high-level control structure. During a walk, humans do not know numeric values how far they are from the closest obstacle or how fast they run. They have a linguistic, i.e. symbolic information in the mind that their relative position is in the range "near-far" i.e.: very near (beside), near, moderately far, far, very far (indefinite far). Similar values gradation is appeared with the forward speed v e.g.: immobile, very slow, slow, moderately fast, fast, very fast. Concerning the dimensions of the obstacles (height, width, depth) the following descriptive indicators are of importance: very small, small, moderate, large and very large/huge. The mentioned linguistic/symbolic indicators/states can be mathematically formulated using fuzzy functions. A robot can be learnt to distinguish the mentioned ranges of symbolic/linguistic indicators in order to predict desired motion in a 3D-world free of collision. Implementing fuzzy rules and fuzzy reasoning in the scope of the cognitive control block, robot will be capable to understand environment and to make appropriate decisions to response to the real circumstances in surrounding. In that sense, elements of artificial intelligence will be incorporated into the biped robot control structure to extend the existing cognitive system behavior. The fundament of the robot artificial intelligence to be built in the advanced intelligent control structure, makes a corresponding cognitive block. It consists of a corresponding artificial connectionist structure as well as a fuzzy system. Both tools enable robot fast learning, environment understanding as well as decision making capabilities. To build such an intelligent control structure, corresponding geometry and kinematical scenario model(s) should be developed. For that purpose, the following scenario models of obstacle avoidance as well as collision avoidance are developed. They are presented in Figs. 2 and 3.

As an example of demonstration of the intelligent reasoning that is planned to be implemented with a humanoid robot, some characteristic simulation results are presented in Fig. 4. In that sense, CAD model of an arbitrary environment with stationary obstacles as well as a target trajectory generated by the corresponding cognitive block are illustrated. Simulation results presented in Fig. 4 were obtained by implementation of the HRSP software (Humanoid Robot Simulation Platform, IMP) for a biped robot whose parameters are defined in advance.

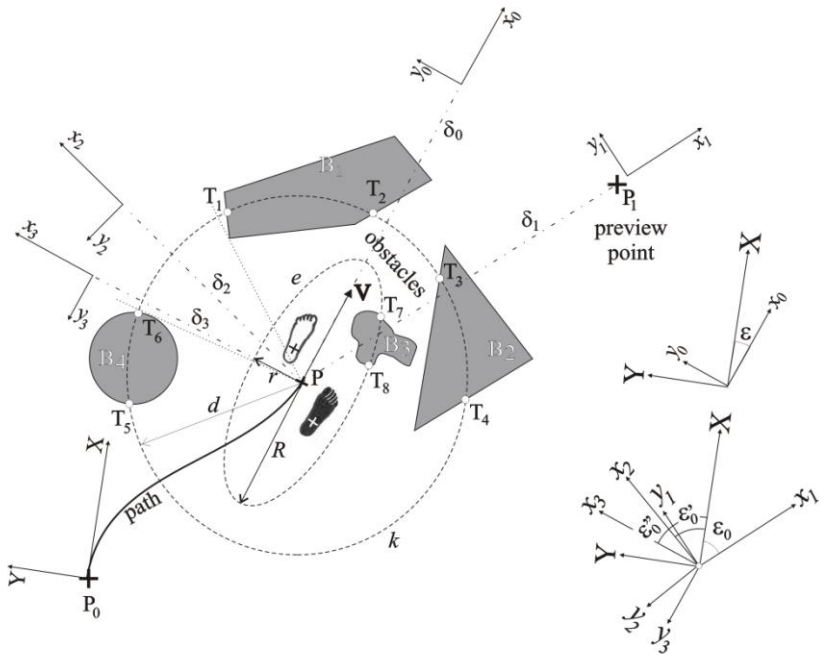

Figure 2: Scenario model of obstacle(s) avoidance - geometry and kinematical indices used for building of cognitive robot block - fixed obstacle avodance

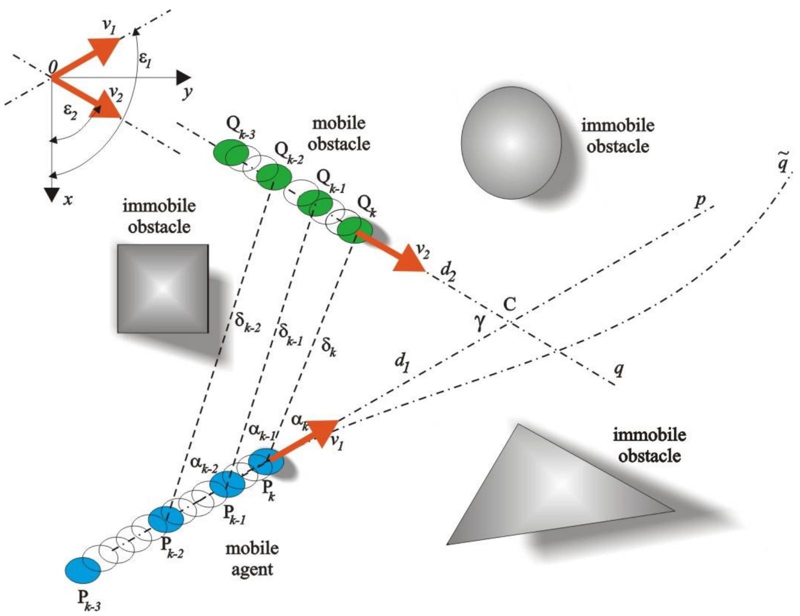

Figure 3: Scenario model of obstacle(s) avoidance - geometry and kinematical indices used for building of cognitive robot block - collision avoidance of mobile objects

Step lengths s (successive distances between the footprints shown in Fig. 4b) and the forward speed v of the biped robot along the target trajectory is determined implementing previously described fuzzy inference engine. For creating fuzzy rules, a simple human logic was imitated. That can be briefly described in few words. If there exist an obstacle in front, decrease the speed, checking possibility to overstep the obstacle (check the height) or move left or right. Adapt the speed of cornering maneuver; track the contour of the obstacle keeping the ultimate direction of moving towards the assumed landmark object (i.e. target point). The actual forward speed of locomotion is adapted in such a way that takes into account the distance from the obstacle as well as yaw rate of the cornering maneuver. Implementation aspects of collision avoidance are conditioned by the technical limits of the biped robot (e.g. robot speed during the maneuver) as well as by processing time. Once, when the target trajectory is determined by the cognitive block of the biped robot system, it is a relatively easy task to synthesize a robot gait. Joint trajectories of biped robot are determined by calculation of its inverse kinematics. For that purpose, using the experimental measurements from the capture motion studio (in order to ensure bio-inspired, anthropomorphic locomotion), the soft-computing algorithms based on artificial neural networks as non-linear identifiers are derived. The multi-layer network structure chosen to train the inverse robot kinematics uses Cartesian coordinates of hip joint centers, hip link mass centers and feet cycloids of motion. At the output it gives generalized coordinates of biped legs that enable robot locomotion in an anthropomorphic way. Joint angular velocities and corresponding accelerations are calculated by numerical differentiation. Joint trajectory tracking, posture stability and dynamic balance will be ensured using *position/velocity feedback* in joint space, *impedance control* as well as *feedback upon dynamic reactions* (i.e. Zero Moment Point ZMP) at the feet soles. Control of biped robot dynamics will be realized at the low-control level (servo level) using the corresponding sensor system (encoders, tension/torques sensor, gyro, etc.). Additional contact force/torque sensors attached to the feet soles of the biped robot are necessary. For that purpose, industrial Force Sensing Resistors or 6-axial Force-Torques sensor are used.

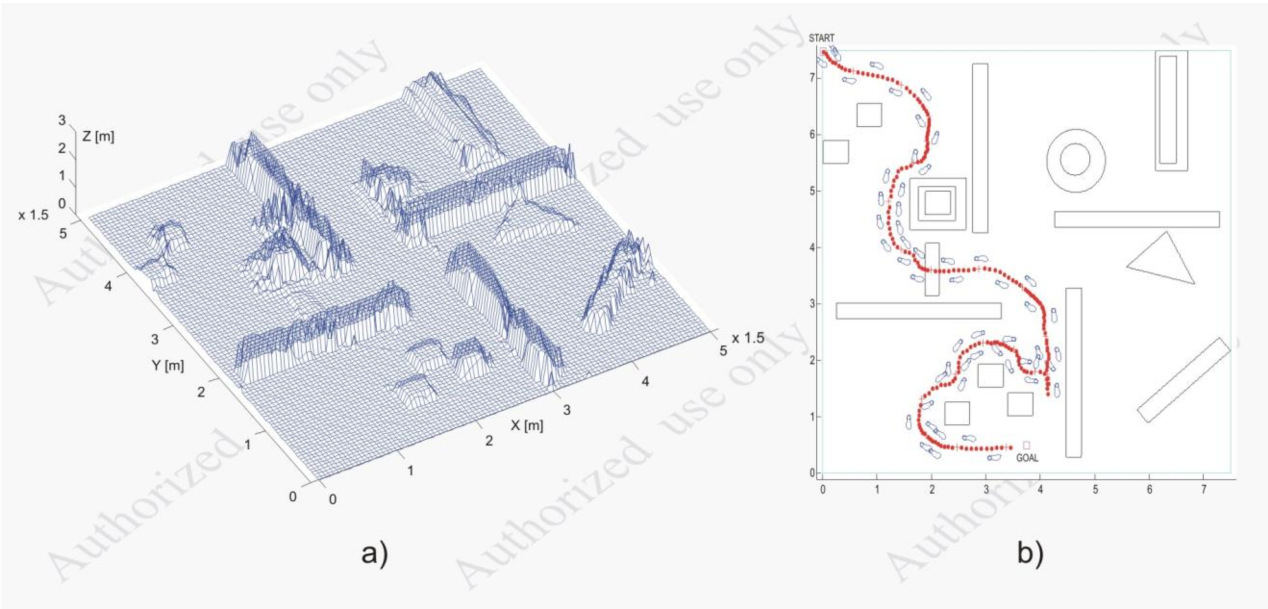

Figure 4: Example of an intelligent autonomous locomotion in unknown environment: a) CAD-model of the environment, b) Obstacle avoidance and target trajectory prediction with the corresponding footprints

Previously described control algorithms will be implemented within the control system structure shown in Fig. 5. Two control blocks represent a brain of the system consisting of *high-level control block* (i.e. cognitive block) and *low-level servo control block*. Control of robot dynamics (biped locomotion) will be designed at the servo-level while the intelligent control algorithms (cognitive behavior) enabling non-restricted autonomous locomotion and advanced reasoning will be synthesized at the high control level. Corresponding data-acquisition blocks ensure state feedback (block 1) as well as information (actual relative position, distance range, obstacle position and velocity, etc.) about world in surrounding. Relay station enables reliable communication between these two hierarchical levels via Ethernet lines. Certain upgrade of the human-robot interface will be done according to the chosen demonstration (simulation) scenarios in order to enable task definition: introducing of the start and goal sites/positions, memorizing of the object image to be found and manipulated, understand of manual and/or sound commands by human operator, etc.

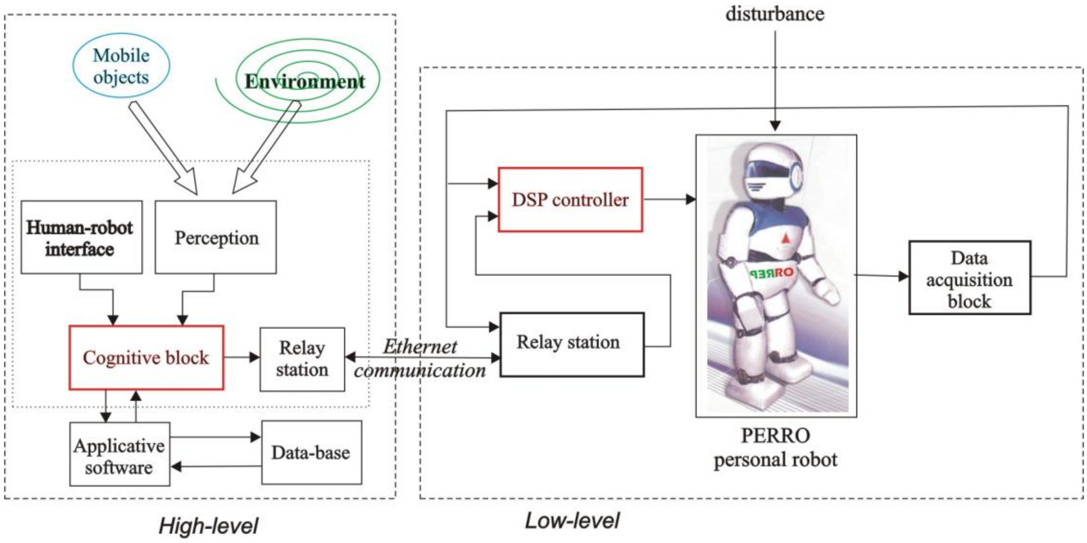

Figure 5: Control system architecture providing an intelligent autonomous locomotion of biped robot