A Probabilistic Motion Planning Algorithm for Realistic Walk Path Simulation

P. Agethen[1,3], T. Neher [1], F. Gaisbauer [1,3], M. Manns[2] and E. Rukzio[3]

[1]Daimler AG, Wilhelm-Runge-Str. 11, 89081 Ulm, Germany
[2]University of Siegen, Paul-Bonatz-Str. 9-11, 57076 Siegen, Germany
[3]Ulm University, James-Franck-Ring, 89081 Ulm, Germany

Abstract

This paper presents an approach that combines a hybrid A path planner with a statistical motion graph to effectively generate a rich repertoire of walking trajectories. The motion graph is generated from a comprehensive database (20 000 steps) of captured human motion and covers a wide range of gait variants. The hybrid A* path planner can be regarded as an orchestration-instance, stitching together succeeding left and right steps, which were drawn from the statistical motion model. Moreover, the hybrid A* planner ensures a collision-free path between a start and an end point. A preliminary evaluation underlines the evident benefits of the proposed algorithm.*

CCS Concepts

•***Computing methodologies*** → ***Animation;*** *Model development and analysis; Motion capture;*

1. Introduction

The simulation of human motion has emerged during the last decades, both in academia and industry. In particular, the ability to precisely predict real-world observations has shown to be a key technology for various domains ranging from production planning over the entertainment industry to the healthcare sector, to remain competitive. For instance, mass-customization is currently increasing the complexity of production within the automotive industry, since the vast majority of produced cars are unique choices from a large set of feature combinations. As one consequence, the simulation of walk paths occurring in final assembly lines is becoming increasingly important.

Within the manufacturing industry, walk paths are usually planned with regard to the assembly operator's root trajectory (center of mass). For this purpose, existing literature presents a broad spectrum of motion planning approaches, which either neglect the statistical nature of human motion or are partly applicable to this use-case. Even though being ideally suited to generate an abstract representation of travel routes, deterministic algorithms such as [HNR68, PEF*12] do not cover the variant-rich spectrum of human locomotion. As a consequence, actual walk paths can significantly deviate from their simulated counterparts [AOGR16]. On the other hand, elaborate approaches which are related to character animation (see Min and Chai [MC12]) enable the generation of a rich repertoire of motions using statistical models. However, the model generation requires exhaustive motion capture datasets - as shown by [MMM16] - while most of the contained information is not needed for the use-case of walk path simulation.

To overcome these drawbacks, this paper presents a novel motion planning algorithm which is tailored to effectively generate statistically distributed center of mass trajectories. The following gives an overview of the proposed concept.

2. Concept and Implementation

The proposed algorithm combines a hybrid A* path planner [PEF*12] with a statistical motion graph - in spirit of the main idea being presented by Min and Chai [MC12]. Following Kovar et al. [KGP02], a realistic motion trajectory between a start and a goal configuration can be generated by means of linking together multiple motion primitives. For instance, a walk motion can be composed from a series of gait cycles. Figure 1 illustrates the proposed approach. It can be seen, that the walk path of a virtual human is generated by means of stitching together succeeding left p_L and right p_R steps. Within this paper, each primitive is drawn from a statistical model, which is constructed using a comprehensive set of captures motions. As this sampling-based approach is capable of generating an infinite number of different motion primitives (see [MC12]), consequently, an infinite variety of trajectories between a given start and an end point can be obtained.

However, as the arbitrary combination of primitives will lead to unnatural results, succeeding left and right steps have to be matched regarding continuity of motion. Moreover, pairs of primitives must be physically feasible and reasonable. To meet these

DOI: 10.2312/egp.20181009

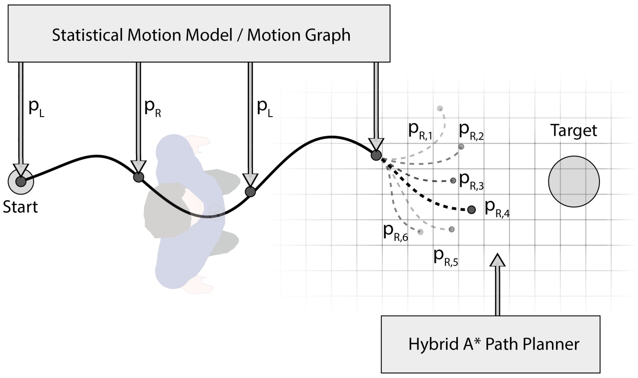

Figure 1: *Concept of proposed algorithm .*

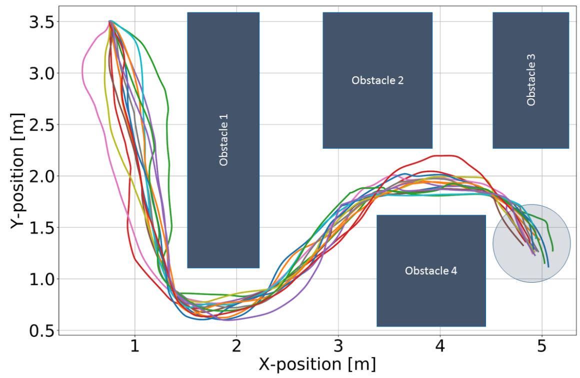

Figure 2: *Exemplary results of the proposed approach in a bird's eye view.*

criteria, a multidimensional function approximation, i.e., Gaussian Processes [PVG*11], is used to statistically model transitions between consecutive motion primitives. To train this model, a comprehensive motion capture dataset was generated, comprising 12 participants and five hours of walking. This database was set-up using an OptiTrack system (14 cameras) and contains approximately 20 000 steps, which were automatically segmented using floor-contact points. Moreover, it is assumed that successions of two captured consecutive motion primitives are reasonable, feasible and continuous, since they have in fact been performed by real human subjects. To train the transition-model using supervised learning, each captured motion primitive is represented by a B-spline. Subsequently, predecessors and successors pairs are fed into the Gaussian Processes model. Using this approach, it is possible to obtain a novel continuous, physically feasible and reasonable motion primitive for given predecessors by means of drawing a sample from the transition model. Note that the initial step (without predecessors) is drawn from an independently trained Gaussian KDEs model [JOP*01], which is established using the identical database and preprocessing pipeline. In contrast, this generative model does not consider transitions between motion primitives.

Even though each generated atomic root trajectory will fit to its preceding counterpart, an arbitrary combination of p_i might not lead to the target destination - or violate collision constraints. Figure 1 depicts this problem. Some of the six sampled motion primitives $p_{R,1,\ldots,6}$ will lead to detours (e.g., $p_{R,1}$, $p_{R,2}$ and $p_{R,5}$), or might result in unnecessary short stride lengths (see $p_{R,3}$). Therefore, the statistical model is integrated into a hybrid A* [PEF*12] path planning algorithm. Similar to the A* approach [HNR68], this adapted version divides the scene into cells and optimizes transitions between cells using a heuristic function. In contrast, the hybrid A* also allows continuous positions within cells, which enables the assessment of motion primitives' end points. In general, the sampled p_i trajectories define all possible actions within each expand step. Metaphorically, each sample's applicability for a given configuration can be determined using the hybrid A* methodology. For Figure 1, this iterative process would accept $p_{R,4}$. Next, the sampling process will be repeated using $p_{R,4}$ as new predecessor.

Figure 2 shows 15 trajectories in a bird's eye view being generated by the novel algorithm, which is implemented in Python. It can be seen, that on the one hand, smooth, short and collision-free paths are obtained, which consider the human gait cycle. On the other hand, the novel algorithm predicts the statistical nature of human locomotion as the 15 trajectories are unique. The mean computation time for each trajectory was .5 s.

3. Conclusion and Outlook

This paper proposes an integrated motion planning algorithm combining a statistical motion model with a hybrid A* path planner. Being built upon a comprehensive set of motion capture data, the novel approach generates realistic and unique motion trajectories. Future work will extend, holistically evaluate and optimize the presented algorithm.

References

[AOGR16] AGETHEN P., OTTO M., GAISBAUER F., RUKZIO E.: Presenting a Novel Motion Capture-based Approach for Walk Path Segmentation and Drift Analysis in Manual Assembly. *Procedia CIRP 52* (2016), 286–291. 1

[HNR68] HART P., NILSSON N., RAPHAEL B.: A formal basis for the heuristic determination of minimum cost paths. *IEEE transactions on Systems Science and Cybernetics 4*, 2 (1968), 100–107. 1, 2

[JOP*01] JONES E., OLIPHANT T., PETERSON P., ET AL.: SciPy: Open source scientific tools for Python, 2001. 2

[KGP02] KOVAR L., GLEICHER M., PIGHIN F.: Motion graphs. In *ACM transactions on graphics (TOG)* (2002), vol. 21, ACM, pp. 473–482. 1

[MC12] MIN J., CHAI J.: Motion graphs++: a compact generative model for semantic motion analysis and synthesis. *ACM Transactions on Graphics 31*, 6 (Nov. 2012), 1. 1

[MMM16] MANNS M., MENGEL S., MAUER M.: Experimental Effort of Data Driven Human Motion Simulation in Automotive Assembly. *Procedia CIRP 44* (2016), 114 – 119. 1

[PEF*12] PETEREIT J., EMTER T., FREY C. W., KOPFSTEDT T., BEUTEL A.: Application of Hybrid A* to an autonomous mobile robot for path planning in unstructured outdoor environments. In *Proceedings of ROBOTIK 2012; 7th German Conference on Robotics* (2012). 1, 2

[PVG*11] PEDREGOSA F., VAROQUAUX G., GRAMFORT, ET AL.: Scikit-learn: Machine learning in Python. *Journal of Machine Learning Research 12* (2011), 2825–2830. 2