Human Motion Prediction Framework for Safe Flexible Robotized Warehouses

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***Abstract*— With the substantial growth of logistics businesses the need for larger warehouses and their automation arises, thus using robots as assistants to human workers is becoming a priority. Worker safety and system efficiency are paramount in such flexible warehouse systems. Dealing with uncertainties in human motion is one of the challenges that an automated warehouse system must tackle. Given that, it is crucial to ensure that human motion is estimated and predicted precisely and in real time. We define the human motion prediction problem in automated warehouses and propose a simulation framework and method to solve it.**

I. INTRODUCTION

The substantial growth of logistics business in recent years has generated the need for larger and more efficient warehouse systems where humans and robots closely collaborate and work together. Such a flexible robotized warehouse system has to ensure that the worker is assisted and not impeded. In order to achieve that, it is necessary to precisely estimate and predict human worker motion.

Precise human motion prediction is crucial to any human-robot interaction system which takes safety and efficiency into account. It is a central building block for an automated risk assessment with its application ranging from mobile robot navigation, autonomous driving, video surveillance to object tracking [1]. Besides different mathematical frameworks that human motion prediction models use, they also differ in the information that is provided. Models can use observation of the agent's position extracted by, e.g., visual tracking or a wearable device or abundant contextual information such as head orientation, environment features [2] and human-human or human-space interactions. The spatial context of motion can be learned by training a model on observed positions of a particular scene, but it is not guaranteed that the model will successfully capture spatial points of interest. One of the drawbacks of state-of-the-art models based on deep learning and recurrent neural networks, such as long short-term memory [4], is using preprocessed inputs without noise. Such models are difficult to incorporate in a realistic system that has to take uncertainty and risk into account. In this paper, we propose a solution to human motion prediction problem in flexible automated warehouses that contain multiple autonomous ground vehicles (AGVs). This problem differs from the pedestrian motion prediction problem in [1], because the motion of the warehouse worker is heavily influenced by the predefined goals (e.g. exits, picking stations) as well as moving obstacles, i.e., AGVs. Given that, it is necessary to reason about worker goals if we want to infer its future path precisely. Our solution relies on our earlier result proposed in [5] and we evaluate it using average displacement error (ADE) method described in [6].

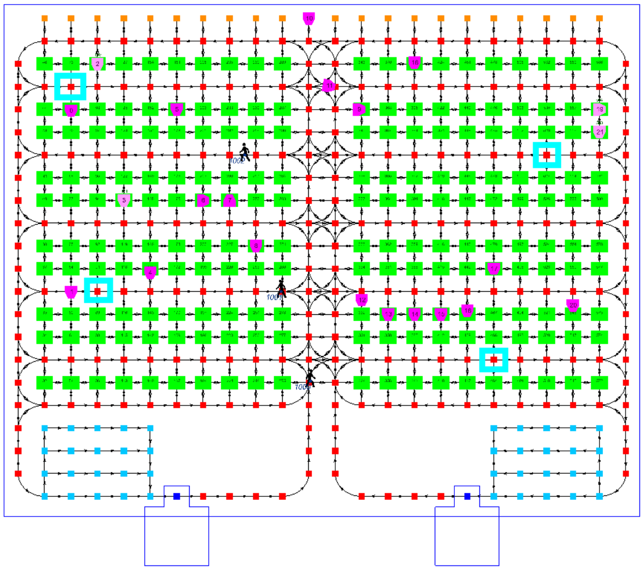

Fig. 1: The automated flexible warehouse simulator used for experiments and testing. AGVs (pink) do a predefined set of tasks such as carrying racks (green) while moving on the ground nodes (red). Three human workers move freely between the racks picking objects at specified warehouse locations or do maintenance work.

II. HUMAN MOTION PREDICTION

In order to conduct experiments, we used a simulation environment shown in Fig. 1 that was developed for testing planning algorithms [7], [8] for flexible robotized warehouse. All AGVs are controlled by the planning algorithm proposed in [7]. The worker can perform tasks such as maintaining the robots or picking the items from specified racks. We assume that there is a finite number of possible goal locations, which are usually in front of the racks of interest. For current

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experiments, we selected four goals, each one in a different corner of the warehouse and their locations are labeled with cyan rectangles shown in Fig. 1. It is important to emphasize that the worker is not required to go to predefined goals, but they do serve as starting points for the proposed algorithm.

First, we calculate the distance between all the ground nodes using the D* algorithm and save it in the distance matrix **F**. In case of a robot blocking the edge between two nodes during runtime, we cut the edge and recalculate the distances. Every time a worker makes a significant displacement, we update its predefined goals intention estimate using a scaled down version of the algorithm proposed in [5], which for brevity we describe briefly and direct the reader to the original paper for details. We associate the position of the worker with the observable nodes by forming a so-called *association vector* **c**. The closer the human is to the node, the larger the value of the vector **c**. By multiplying **c** and **F**, and by isolating the goal nodes, we obtain a modulated distance vector **d** of dimension g, where g is the number of goals. We also calculate the alternative association vector **c'** of the positions the worker might have gone to, if it moved the same distance from the last observation; we also calculate the corresponding modulated distance vector **d'**. By comparing values of the vector **d** with values of each **d'** that we collect in matrix **D**, we calculate the observation vector **v** via element-wise division:

$$\mathbf{v} = \frac{\max\limits_{1\leq i\leq n} \mathbf{D}_{ij} - \mathbf{d}}{\max\limits_{1\leq i\leq n} \mathbf{D}_{ij} - \min\limits_{1\leq i\leq n} \mathbf{D}_{ij}}. \tag{1}$$

If the worker is moving towards the goal, the corresponding value of **v** will be close to unity, and if it is moving away from that goal, the corresponding value will gravitate to zero. We record the observation history and process it with an HMM model and the Viterbi algorithm outputting probabilities of the worker going to each goal, which we consider as intention estimations. Using the D* algorithm on warehouse nodes in Fig. 1 we find the shortest path towards each goal. Then, we predict worker's future motion with respect to goals by interpolating the D* paths using the assumption of constant velocity. Finally, after obtaining the path towards each goal, we find the expected path by weighting each path with the intention probability towards that goal. The results of the proposed algorithm can be seen in Fig. 2 and in accompanying video[1], where we show that proposed model yields 1.084 m average displacement error (ADE) with respect to the prediction horizon. The results can be compared with linear interpolation which yields 1.1186 m ADE but often predict untraversable path or unreachable positions because of autonomous robots blocking the path.

III. CONCLUSION

In this paper, we have proposed a framework for human worker motion prediction in flexible robotized warehouses. We observe worker locations and estimate their intentions by exploiting the observed and hypothesized motions. Using the computed intention estimates, expected worker paths were predicted. We evaluated worker motion prediction accuracy in simulations by calculating the average displacement error with respect to the prediction horizon.

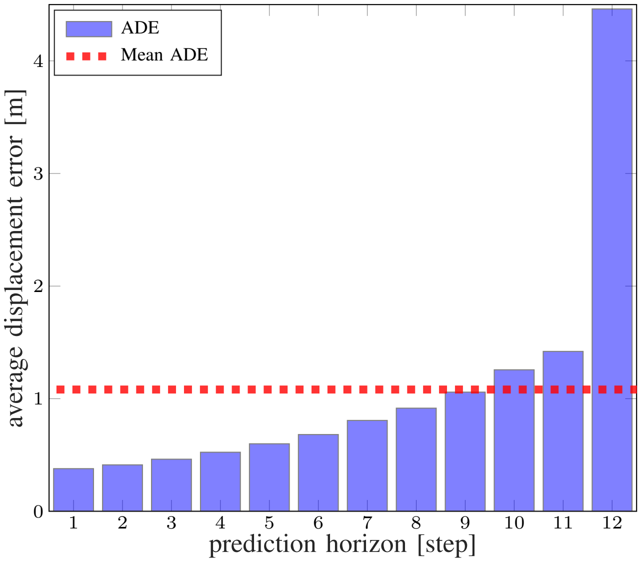

Fig. 2: Human motion prediction results. We observe past 8 worker locations and predict the next 12 as in [1].

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