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Validation of RoboGuide to Support the Emulation of Sporting Movements using an Industrial Robot

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Abstract

Mechanical testing plays an important role in the development of athletic footwear. Typically, these tests do not accurately represent the forces and motions the footwear experiences during human use and there is substantial scope to improve this situation. The purpose of this study was to assess the extent to which RoboGuide software can be used as a virtual environment to support the emulation of the ground contact phase of human locomotion on a FANUC™ six degrees of freedom industrial robot. A series of simple (linear and corner) and complex (sagittal plan heelstrike running) movements were completed on both the robot and RoboGuide using the same input kinematics. The effect of movement velocity, level of robotic smoothing and number of co-ordinate points defining the trajectory were also investigated. The resulting movement and timings on the robot and Roboguide were compared to the input kinematics as well as to each other. The results indicated small differences in the robot and RoboGuide trajectories for simple linear motions (< 30 mm), that became much greater for the complex footstrike motion (~ 100 mm). These differences were affected by levels of smoothing and movement velocity and, notably, only with no smoothing did the robot and Roboguide approach the input trajectory. To conclude, RoboGuide does not accurately represent the motion of the FANUC™ robot and therefore only has limited use in supporting the physical emulation of complex sporting movements.

Keywords: Athletic footwear; mechanical testing; 6 DoF industrial robot

1. Introduction

The modern running shoe industry began in the 1970’s and has grown to be worth $13 billion per annum globally [1]. Leading running shoe companies currently invest large amounts of money into

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product research and development, with mechanical testing remaining a focus. Mechanical wear testing aims to evaluate the performance of a shoe under realistic use conditions [2]. Examples of such devices include the Wheel Wear Machine (WWM) developed by adidas to replicate walking and running gaits [3], the Pedatron STM528 test machine [4] designed by SATRA as a walking footwear-surface abrasion tester and the Stewart Platform, intended to replicate force application [5]. These devices have a number of advantages over human testing, such as the ability to complete large numbers of ground contacts in short timeframes. However, their ability to generate ground contacts similar to that of human locomotion remains a major issue, e.g. the WWM has a running ground contact time over three times longer than a human (~0.6 s versus ~0.2 s) [3].

Challenges remain in the development of a biofidelic mechanical test devices for athletic footwear. More recently, the potential of an established multi-dimensional kinematically-controlled robot with recognised control systems was investigated as an alternative method to emulate the ground contact phase of human locomotion [6]. The Japanese FANUC^{TM} R-*2000i*-B 6 Degrees-of-Freedom (6 DoF) industrial robot was used to emulate heelstrike and forefoot running gaits over 500 ground contacts. The robot kinematics were found to be highly repeatable (<1.5mm average SD in trajectories) however issues were reported regarding the timescale of ground contact and trajectories compared to the original human data. Three variables were identified as influencing how well the actual robot movement matched the original human movement: level of robotic smoothing (higher levels ensured a “natural” smooth movement); movement velocity; and the number of data points used in the footstrike programme.

One of the accompanying tools provided with the FANUC^{TM} robot, is the computer software RoboGuide, which simulates the robot in a virtual environment. The robot’s environment, layout and motion scan be simulated giving the advantage of not having to alter real world parameters until potential benefits are assessed. Results from a more traditional industrial setting (Jin and Yang 2009) have shown that fast-track programming using RoboGuide can help to reduce robot downtime and make the manufacturing process more efficient [7] & [8]. RoboGuide can be used to manipulate the virtual robot as in the real world and these kinematics can be evaluated using a number of analysis features, trajectories can be monitored and measured, the built in timers and collision detect feature can also be used for further analysis as well as the ability of recording movements to a video file. As such, this software also has the potential to support research into the development of human emulations on the FANUC^{TM} robot.

The robot has a number of programmable and embedded features within its control system that affect its resultant motion; it remains unknown whether these features have also been built into RoboGuide. Some literature has compared a 90º rotation on the robot and RoboGuide and found the finishing position to be the same in both cases [9], no study has attempted to compare the complete trajectories of RoboGuide versus the robot based on the same input programme. For applications in emulating the ground contact phase of human locomotion a detailed comparison of RoboGuide kinematics versus the robot is necessary in order to assess the degree to which RoboGuide can be used to support the development of the emulation of complex sporting motions on the FANUC^{TM} robot. Hence, this study aimed to compare the kinematics (trajectories and movement timings) of RoboGuide versus the robot using initially a number of simple one and two dimensional movements followed by the more complex movement of human heelstrike running.

2. Methodology

Two sets of trials were conducted: (1) simple vertical, horizontal and 90° corner movements (the first two involving a 400 mm displacement from the start point to the turnaround point, the corner involving a 400 mm displacement from the start point to the corner and a further 400 mm to the turnaround point); and (2) sagittal plane heelstrike running based on human kinematic and ground reaction force data

(Fig. 1). In each case, the resulting movement on the robot and RoboGuide were measured and comparisons made between the programmed movement and the actual movement.

For set (1), the effects of robotic smoothing (maximum, middle & none), movement velocity (500 mm/s, 100 mm/s & 1500 mm/s) and number of additional co-ordinate points used to define the movement (end points, end points + 1 & end points + 2) were varied. Trials were performed for every combination of the above variables on the robot and RoboGuide (a total of 81 trials on each). The robot movement was recorded using a high speed video camera (SA 1.1, 1000Hz; Photron FastCam- Buckinghamshire, UK). The robot spike end-effector was generated as a CAD file and imported into RoboGuide, where the movements were measured using built-in measure and timing tools and video capture of the on-screen movements. For set (2), human heelstrike running data was collected for one subject using Vicon (1000 Hz; Vicon, Oxford UK) and a force platform (Kistler 9281CA, 1000 Hz; – Hampshire, UK). The sagittal plane kinematics of the heel marker and long axis of the foot (trajectory, velocity and orientation) from 2 seconds before impact to 0.5 seconds after impact were used to programme the robot and RoboGuide using the maximum level of robotic smoothing in order to remove any stutter from the movements. The resulting movement on the robot was captured using CODA (CODA CX1, 1000Hz; Charnwood Dynamics – Leicestershire, UK), the same force platform as in the human data collection and a shod prosthetic foot end-effector. For Roboguide, the movement capture was similar to set (1) where the force platform and shod end effector were generated as a CAD files and imported into RoboGuide. RoboGuide does not model the interaction between the end-effector and force platform but can return when the collision detection is positive, i.e. the end effector is in contact with the platform. Two heelstrike programmes were used: one to run over the force platform as in the human running trial; and the second in mid-air (by offsetting the programme vertically) in order to assess the resulting movements without the force platform affecting the non-rigid shod end-effector (robot only).

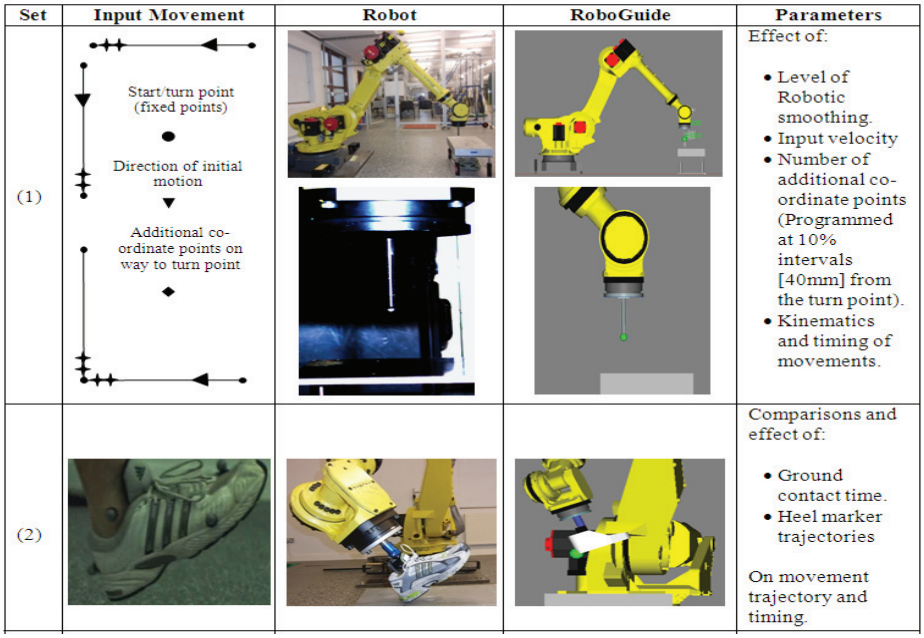

Fig. 1. A summary of the two sets of trials completed on both the robot and RoboGuide, showing input movements, rbt and RoboGuide positions and the investigated parameters

For set (1) the robot videos were digitised at 100 Hz using Image Pro Plus (Media Cybernetics, Inc. USA) to obtain the 2-D co-ordinates of the spike tip throughout each movement. The measure tools in the

RoboGuide software outputted the position data of the spike tip against the programmed values. For the corner trajectories, the video file (125 Hz) of the computer software motion was digitised for comparisons against each other. The built-in timer provided timing information for all movements. For set (2), the force platform data was analysed to determine ground contact time, while for RoboGuide this was established using the collision detect feature and visual inspection of when ground contact occurred.

3. Results

Displacements (start to turn point) for the vertical motion on the robot and RoboGuide for the different smoothing levels, velocities and co-ordinate points applied are shown in Figs 2 – 3. The general trend for both the robot and RoboGuide was for the displacement to drop as the level of robotic smoothing or velocity was increased or fewer additional co-ordinate points were used. The RoboGuide displacements tended to be slightly greater than for the robot (by up to 30 mm). For the robot, the programmed displacement of 400 mm was only reached when no smoothing was used with lower velocities and additional co-ordinate points. For RoboGuide, the programmed displacement of 400mm was reached whenever no smoothing was used. At the other extreme, i.e. maximum smoothing and higher velocities, the displacements only reached two-thirds of the programmed value (~ 250 – 270 mm). Very similar results were obtained for the horizontal motion. The total movement time and time taken to reach the turn point for the vertical movement on the robot and RoboGuide for different levels of robotic smoothing are shown in Fig. 4. Generally, as smoothing level was reduced movement time increased. The robot tended to take longer moving from the start point to the turn point compared to returning to the start point, whereas the opposite was observed on RoboGuide particularly at higher smoothing levels. Similar results were observed for horizontal and corner movements.

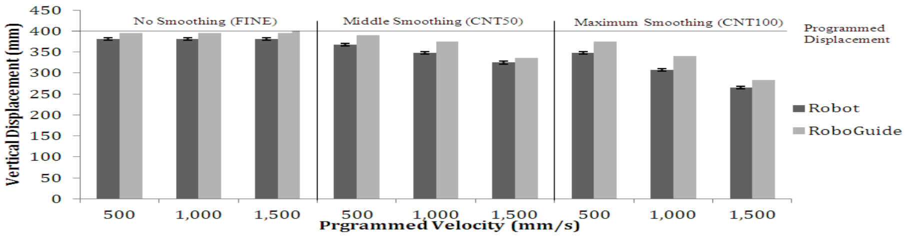

Fig. 2. Vertical displacement from start point to turn point (programmed displacement was 400 mm) for the robot and RoboGuide with different levels of robotic smoothing and velocity (using no additional co-ordinate points)

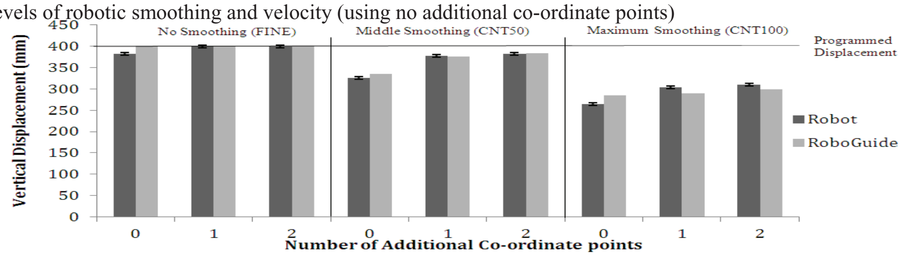

Fig. 3. Vertical displacement from start point to turn point (programmed displacement was 400 mm) for the robot and RoboGuide with different numbers of additional co-ordinate points and levels of robotic smoothing (using a velocity of 1500 mm/s)

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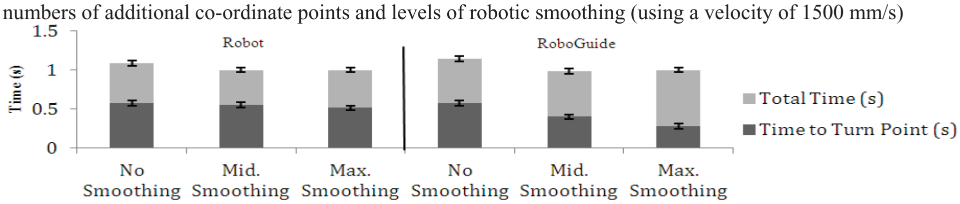

Fig. 4. Vertical movement times, to turn point and total, for the robot and RoboGuide at various smoothing levels

Typical trajectories of the robot and RoboGuide for the corner movement are shown in Fig. 5. As smoothing level and velocity were increased both the robot and RoboGuide trajectories moved further from the corner point. When additional co-ordinate points were used the trajectory was pulled back closer to the corner point. For no smoothing and 500 mm/s both the robot and RoboGuide moved very close to the corner point regardless of the number of additional co-ordinate points. As for the vertical movement, there were small differences (up to 8 mm) between the robot and RoboGuide trajectories.

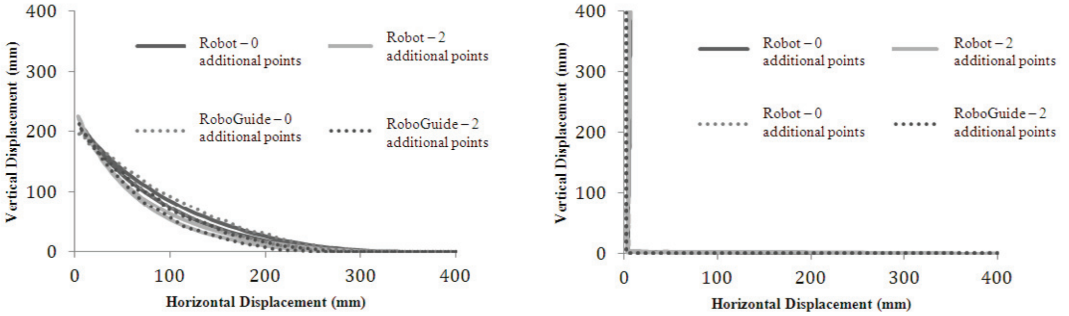

Fig. 5. The corner movement trajectories for the robot and RoboGuide with different numbers of additional co-ordinate points (+ 0 and + 2) with **(a)** Maximum smoothing at 1500 mm/s; and **(b)** No smoothing at 500 mm/s

The heel marker trajectory for the heelstrike running trials is shown in Fig. 6, where the robot and RoboGuide trajectories are for the mid-air trials. The RoboGuide trajectory was far closer to the human trajectory compared to the robot, deviating typically by < 10 mm. In comparison, the robot had a shallower approach angle during early stance and similarly at take-off, and the trajectory differed markedly from the human data during mid-stance, i.e. foot flat on the ground with minimal heel marker movement. From the force platform trials, the ground contact time for human running was 0.209 s, but much higher for both the robot (0.656 s) and RoboGuide (0.584 s).

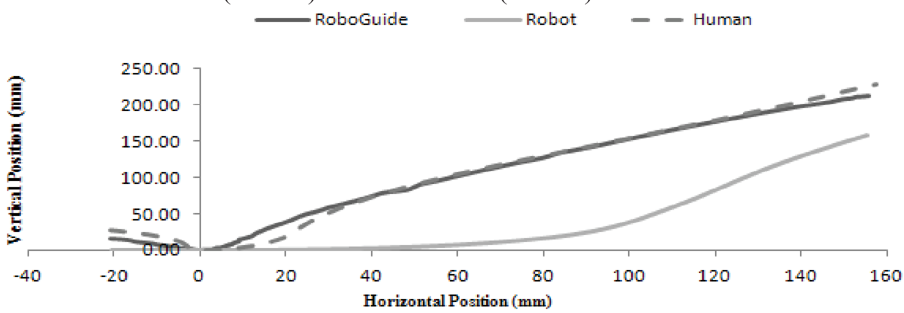

Fig. 6. Heel trajectory data for heelstrike human running, the robot and RoboGuide throughout the ground contact phase, which starts at 0 mm in the vertical & horizontal plane, trials star t 20 mm horizontally prior to initial contact, ending 150 mm after contact

4. Discussion

This study aimed to determine the potential of RoboGuide to support the human locomotion emulation on the FANUC^{TM} robot, through a comparison of the kinematics and timings of simple and more complex (footstrike) movements on each. The results suggest that for a given input trajectory, the resultant kinematics of RoboGuide and the robot exhibit small differences for simple horizontal and vertical motions which become much greater for the more complex ground contact movement. This was observed across a range of movement velocities, levels of robotic smoothing and number of co-ordinate points defining the trajectory, with increased levels of smoothing tending to produce greater differences between the two. Furthermore, neither RoboGuide nor the robot trajectory matched the inputted trajectory unless there was no robotic smoothing, which also resulted in a stuttered movement suggesting that the velocities would be poorly matched. Notably, RoboGuide gave closer agreement than the robot to the inputted movement. One potential reason for the difference between RoboGuide and the robot could be measurement error; however a basic error analysis on both measurement methods (video digitisation for the robot and using the built in RoboGuide measure tool) indicates positional errors of < 3 mm, far smaller than the observed differences. Therefore, it appears that RoboGuide is not programmed to move in the same way as the robot, suggesting that its potential for supporting human locomotion emulation on the robot is limited. The differences in the trajectories between the robot and RoboGuide appeared significantly larger for the heelstrike ground contact than for the linear and corner movements, with the biggest difference occurring midstance where the heel marker velocity was at its lowest (close to 0 mm/s). Further investigation is required to better understand why the differences were so large during this stage and whether they were velocity related. Despite the difference in resulting movement between the robot and RoboGuide, the latter may still be of some use in the physical emulation process, e.g. as a visualisation tool for creating and simulating workspace environments prior to their physical development and as an offline programming tool [8]. The wider scope of this research is to emulate human locomotion on the robot. The results presented here suggest that significant work remains to be done in order to achieve this objective with neither the kinematics nor timing of the movement being closely matched. Although RoboGuide gave a reasonable approximation to the human heel marker trajectory it also gave poor timing data with the footstrike taking almost three times longer than the human foostrike. To conclude, the differences in kinematics and timing between the robot and RoboGuide for a given input suggest that RoboGuide has only limited use in supporting the emulation of complex sporting movements using the FANUC^{TM} robot.

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