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Digital Human Modeling as a Risk Assessment Tool for Maritime Workers

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Abstract. Safeguarding the health of dockworkers in maritime transportation represents a high priority with employer's organizations within the port facilities and maritime organizations. Riggers responsible for container lashing secure a high amount of containers on the ship while working with heavy equipment on a tight schedule and therefore risking musculoskeletal disorders. In addition there is a gap discovered between the learned practices at the training facility and the behavior applied on the work floor. As a result it is necessary to provide a risk assessment tool for maritime workers. Firstly, non-intrusive motion capture method can be used to map their posture and movements with the possibility to emphasize on causing factors of repetitive strain injuries. Secondly, a DHM representing the rigger in maritime environment is created in Blender. Finally, an inertial mocap system is used to monitor kinematic lashing movements and to create a musculoskeletal model. The output can be used to create a framework for future observations with focus on developing a product-service-system (PSS) and smart personal protective equipment (PPE) tools.

Keywords. Wearable Motion Capture Inertial System, Product-Service-System (PSS), Digital Human Modeling, Marine (transportation), Occupational Repetitive Actions (OCRA), Health Monitoring, Marine Workers

1. Introduction

1.1 Background

Dockworkers or stevedores are indispensable in lashing and de-lashing of containers that enter the ports facilities and use a lashing technique conform with the learned craftsmanship respecting the safety measurements and prevailing legislation [1]. Container lashing is one of the high-risk professions in marine cargo [2]. Hence dockworkers responsible for container lashing (riggers) in the harbor of Antwerp can suffer from upper body chronic pains (neck, low back…). Due to continuous involvement of these body parts in lashing and de-lashing operations, the combination

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of a bad posture and incorrect applying force onto the turnbuckle, the risk of musculoskeletal disorders can be increased [2].

Prevention and training play a role in the risk assessment of musculoskeletal disorders in maritime workers. In fact, in Antwerp (Belgium), Cepa (employer's organization) and Ocha (port labor training center) are investing resources for training and prevention, are donating a dedicated training course of lifting techniques and ergonomic behavior to correctly lash containers[3–6].

1.2 Lashing and de-lashing technique

Container lashing is divided into two activities: lashing and de-lashing of containers. A container lashing consists of a turnbuckle and a lashing bar. Within these two domains, riggers work with small and big lashing bars. Small bars are used to constrain containers to the deck of the ship and have a length of 2,5 meters and weight of 11,9 kilograms [7]. The big lashing bars are used for securing containers with the already lashed containers underneath them with a length of 5 meters and weight of 21,1 kilograms [7]. A turnbuckle connects the lashing bar with the deck of the ship while adjusting also the tension on the lashing turnbuckles that have an approximate weight of 12,2 kilograms [8]. Container lashing crews are advised to work in pairs. One rigger (rigger1) raises the lashing bar and locks the top hook in place on the container. While the second rigger (rigger2) is in charge of securing the turnbuckle at the deck of the ship. Both riggers walk towards each other to connect the lashing bar with the turnbuckle (Figure1).

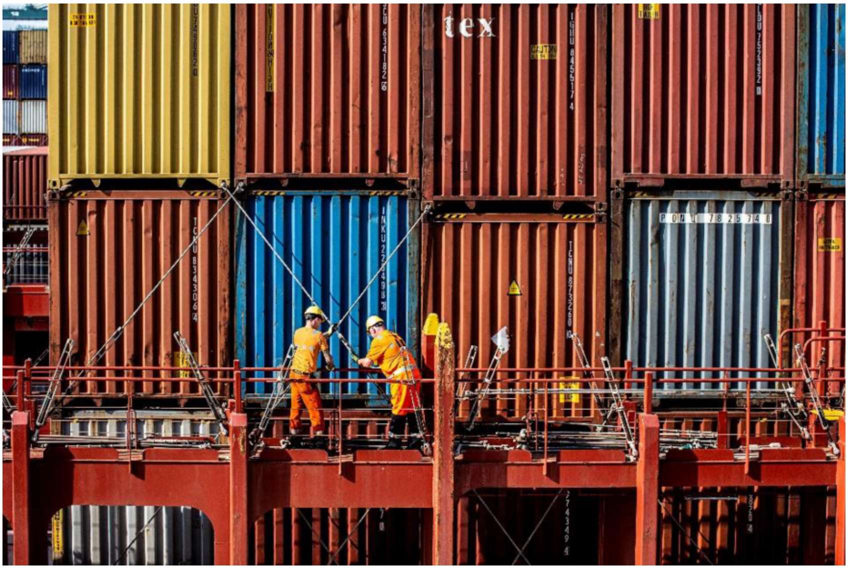

Figure 1. Lashing and de-lashing in Antwerp port (photo courtesy of Cepa).

Rigger 1 is in charge of locking the screw pin shackle from the turnbuckle in the lashing eye connected to the deck of the ship. While rigger 2 holds both items in place, rigger 1 fastens the turnbuckle, using first his hands to tighten and afterwards a fastening tool, which can be a metal bar or a dedicated tool [3–6].

1.3 Aim of the preliminary study

This study seeks to build an identification tool for incorrect behavior shown in previous interviews using motion capture analysis in combination with risk assessment tools. In order to fully understand this abnormal behavior, observations of the current work ethics and methods are required. To that end, a structured observation protocol to monitor container lashing crew and their behavior using at non-intrusive method is presented in this paper.

2. Methods

The validated observational method for motion capturing consists of video-cameras mounted in the environment port. But this method is intrusive because the participants feel observed and as a consequence react to correct their gestures and thus distorting the resulting data [9]. Inertial measurement units (IMU) allow to increase the detail in observational results in comparison with the markerless system available and therefore provide profound observational data [10]. As the usable surface to operate while observing riggers on a ship is very small [1], implementing an IMU in this environment would increase the efficiency of the observation.

2.1. *The Lashing and de-lashing gestures classification*

Using video footage of container lashing, the portrayed movements are classified in 4 different activities divided in gestures made to fulfil the task:

1) lashing with a small lashing bar;
2) de-lashing with a small lashing bar;
3) lashing with a big lashing bar;
4) de-lashing with a big lashing bar.

1) The first activity, lashing with a small lashing bar, consists of the following gestures:
   A. bending forward to reach the lashing bar or the turnbuckle;
   B. leaning forward to tighten the turnbuckle;
   C. leaning forward while having arms stretched out horizontal by before torso to fasten the turnbuckle with a fastening tool;
   D. straighten the posture to rest or reposition the movement;
   E. while in a straight posture raising the arms vertically above the body to lock lashing bar into place.
2) The second activity is lashing containers with big lashing bars. This operation was divided into the following gestures: All the above (A,B,C,D and E) including F.
   F. squatting, holding a straight posture to lift the lashing bar, locking it into place.
3) De-lashing with a small lashing bar is the third activity. The consecutive gestures are:
   A. bending forward to lay the lashing bar or the turnbuckle on the ground or to release the turnbuckle from the lashing eye;
   B. leaning forward to loosen the turnbuckle and to disconnect the turnbuckle from the lashing bar;
   C. leaning forward while having arms stretched out horizontal by before torso to loosen the turnbuckle with tool if necessary;

D. straighten the posture to rest or reposition the movement;
E. while in a straight posture raising the arms vertically above the body to unlock the lashing bar from container.

4) The last activity is described as de-lashing with a big lashing bar. This activity was also divided into smaller gestures: All the above (A,B,C,D and E)

2.2. *Motion capturing*

A test subject performed five repetitions of the four activities that represented lashing and de-lashing in a simulated environment. The test was segmented into two focusses: in the first one the test subject performed the gestures as accurately as possible while the second focus relies on mimicking the gestures from the lashing video footage as accurately as possible. Every activity was performed five times followed by a rest in the N-pose for five seconds between each activity. These gestures were recorded using a wearable motion capturing system called Xsens (MVN Awinda, The Netherlands) [11], and reconstructed in Blender [12].

The emphasis of this test laid on translating the range of motion of the riggers into a Digital Human Model (DHM) representation of the dockworkers gestures while lashing containers. In addition, the kinematics of the dockworkers gestures were also analyzed.

2.3. *DHM for container lashing crews*

A dedicate DHM was created in MakeHuman [13] and imported as COLLADA (.dae) in Blender [12]. Successively the subject was captured during lashing and de-lashing simulation gestures using the mocap system [11] and exported as BVH file [14]. Using the parenting and retargeting tool in Blender it was possible to transfer the motion of the test subject into the human base mesh model [15].

2.4. *Dedicated PSS to visualize potential injuries and its potential origin*

For better understanding of the presented injuries within a maritime environment, a broader observational system should be designed. As validated ergonomic assessment tools rely on empiric manual input [16], an utilization of kinematic data from IMU [11] has the possibility to decrease the margin of error and increase efficiency. Explorative research indicates that PPS implementation in health care is quite novel and therefore provides great potential [17]. In advance of conducting observations a dedicated protocol should be designed. This protocol will prelude as fundament for further iterations of the PSS [18]. Where Bortolini M, et.al. [19] concentrates on implementing kinematic data for higher accuracy and efficiency, our protocol should also focus on transparent communication to the participant and therefore enrich their perspective on injury prevention.

Results from Blender and a mocap system [11] will be combined to visualize problems in a simplified manner and have the ability to train the correct movements without constant supervision of a rehabilitation specialist. The kinematic data retrieved from the IMU [11] was utilized as input data for validated ergonomic risk-assessment tools [19,20]. A 3D model of the dockworker can be integrated with the information of the Anybody software [21] for musculoskeletal modelling simulation giving a predictive vision of the executed gestures from riggers preventing injury and preserving their performances.

3. Results

3.1. *DHM proposal for riggers*

The subject was wearing a full mocap system while performing in a simulated environment as shown in Figure 2 (on the left). Successively, the BVH was imported into Blender and used for rigging the mesh representing the movements performed by a rigger (Figure 2, on the right). A texture was made to embody the rigger's equipment (Figure 3). Containers were created in Blender as OBJ file into Blender to reproduce the digital human system interaction and integration in a virtual environment as in Figure 4. Finally, a virtual or a real scene was added as background (Figure 5).

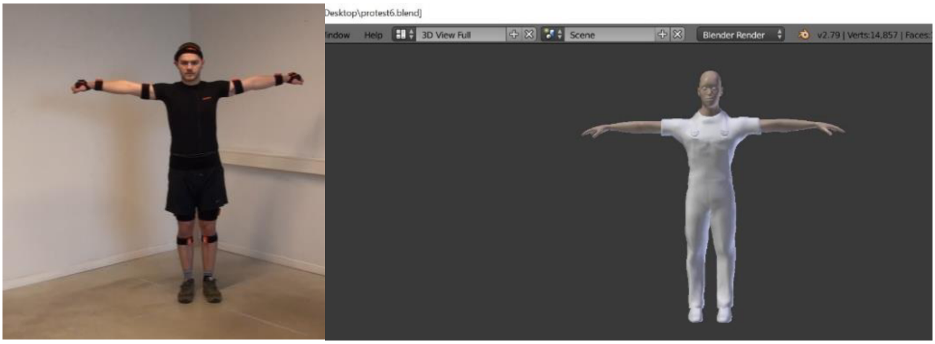

Figure 2. Acquisition of the subject using a mocap system in a real environment (left) and DHM created in Blender (right).

Figure 3. Rigging in Blender.

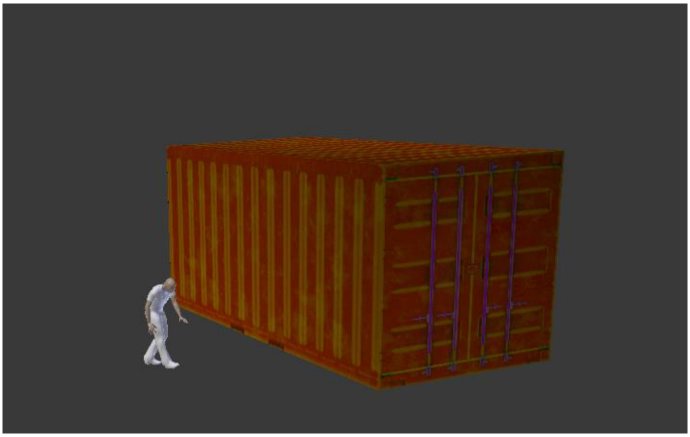

Figure 4. DHM of the stevedores and recreation of a container in Blender.

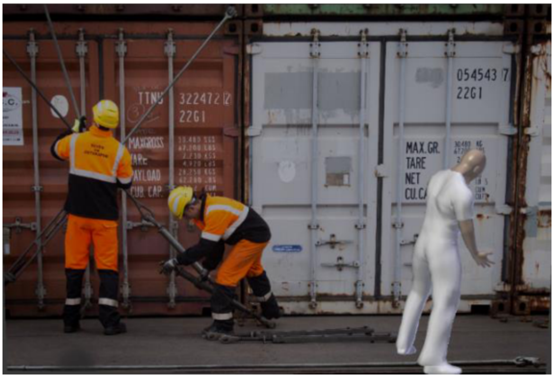

Figure 5. DHM into a real scene.

3.2. *PSS as tool in maritime workplace*

Within the current business environment the ability to reinforce existing business models with the integration of PSS, the focus shifts towards smart PSS [22]. With the presented product-service-system, the emphasis lays on creating a learning system. Focusing on digital resource driven value the PSS has the ability to create a monitorial structure [23]. Clarifying incoming kinematic data and outputting ergonomic suggestions, employer's organization have a risk assessment and training tool for study and improving worker 'safety and well-being, workplace design reducing injuries without affecting their performances. Indeed, the combination of Kinematics, Kinetics and Dynamic data could also constitute a computationally efficient posture and motion prediction of the worker (Figure 6). As a result, the PSS will constitute a valid follow-up for ergonomist, rehabilitation specialist and designer of dockworker system integration and interaction for designing new products, environments, systems and services for improving the quality of work-life of the dockworkers.

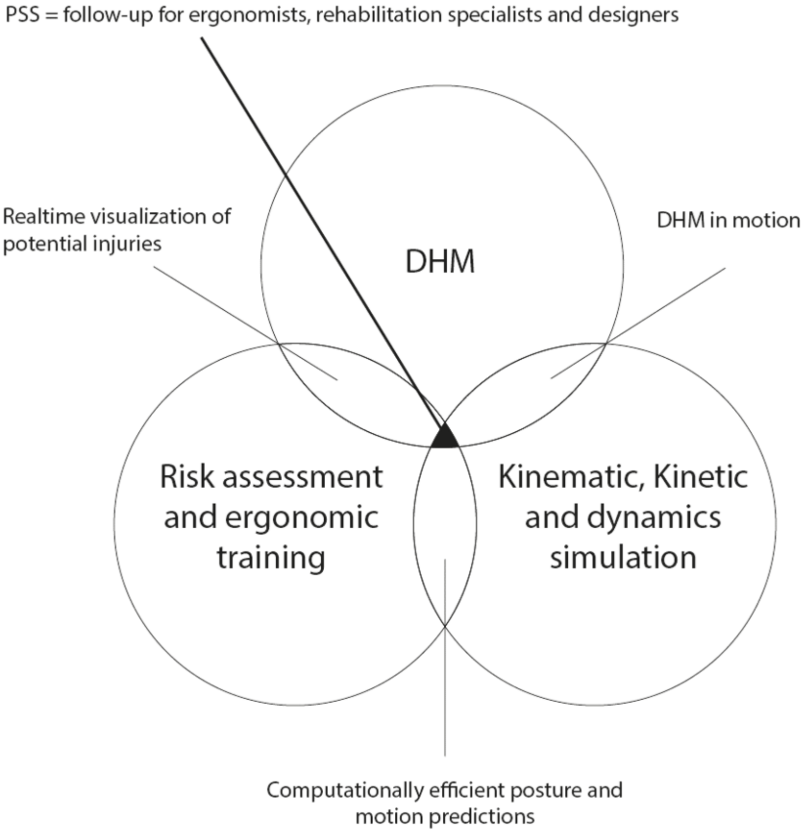

Figure 6. Proposition of a smart PSS as tool in maritime workplace.

4. Discussion

4.1. *Combining IMU and DHM: a trial and error process*

The two IMU systems used to form the baseline for the observations were Wearnotch [24] and Xsens Awinda [11]. Metal interference of the containers and the lashing bars used in container lashings, create disturbance on a IMU that can affect the results. Wearnotch [24] suffered greatly from the interference, not giving a consistent output while working next to the metal containers and shutting down while the test subject held a metal lashing bar. Xsens has experience with countering this metal interference, seen in the cases shown on their website [11]. To secure the more expensive Xsens mocap system [11], the lashing and de-lashing actions were mimicked by a test subject in different environments. Both systems mounting mechanisms provide no additional support in securing the sensors. To minimize potential damage, they are placed underneath the safety equipment made of fabric. Sudden movements or even an acute vibration can cause the sensor to move its position or get damaged. While Wearnotch [24] uses a system where sensors are snapped into clips on straps, these straps are difficult to adjust, resulting in discomfort. Xsens Awinda [11] uses Velcro patches on the back of the sensors and comfortable specified bands with an adhesive surface to ensure a more comfortable experience, but makes securing the sensors more difficult. A preliminary test with two subjects evidenced that the provided gloves and soles for the shoes to mount the Xsens Awinda [11] on, are not comfortable. And consequently it is necessary to redesign them and test them in a broader population.

Kinematic data can be extracted from mocap systems into excel datasheet for evaluating joint angle data of the upper extremity (L5S1, C1, T4 left and T4 right shoulder). These can be included in the model comparing the different gestures made during each activity representing the joint angle of the maritime worker's upper body. Due to the small operational surface to work on while lashing, the high mass of operable equipment and the time sensitive work scheduled, the likelihood of losing one's equilibrium could be a potential threat. Therefore, our protocol will include next to range of motion (ROM) evaluation also posturographic analysis of the workers using the center of mass (COM) of the subject [25].

4.2. *Implementation of a behavioral monitoring system within maritime transportation*

Executing a behavioral monitoring system would be beneficial for long term supervision of riggers and dockworkers. The system can decrease work for instructors, supervisors and physiotherapist while improving the performance of new recruits. The combination of 3D visualization and kinematic information allows expressing a fast and specific solution for sustained injuries. This would grant better interpretation and understanding in performing correct gestures and therefore result in less injuries. Simultaneously a broader comprehension of the work culture should be established. The contribution of service design tools will grant the ability to better understand the work culture and origin of the incorrect behavior.

4.3. *Future perspective on DHM in maritime transportation*

Future perspective will be to address the creation of a dedicated application for linking kinematic data with 3D models to automatically categorize certain movements and give an early diagnose of potential injuries [26][27]. Using Matlab [28] a plugin can be built as prototype for this application and therefore almost directly be included within future observations. Early observations with riggers in the port of Antwerp will monitor not more than 12 participants, due to the voluntarily nature of the enrolment of the participants. Forthcoming tests with the plugin will examine if a machine learning character improves the results shown by the plugin. If the amount of participants would rise in later observation, data will become more detailed and more specific problems can be presented by the application. To further automize the presented system, Statistical Body Shape Modeling (SBSM) can be implemented [29].

Furthermore, thorough research is needed to create a smart protective garment for maritime workers. The combination of intellectual safety equipment and a motion analysis system provides the opportunity to build a product-service-system (PSS) within a maritime environment. A seamless calibration between product and service provides possibilities for increasing workflow efficiency within maritime transportation.

Upcoming research of the implementation of a PSS in the dockworker training program can be extrapolated to engineering PPE for dockworkers resulting in specialized garments regarding the practiced profession [30].

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