Motions effect for crowd modeling aboard ships

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Abstract. Pre-computed ship-motion history has been used in the multi-user Virtual Reality (VR) system VELOS in conjunction with a kinematically-oriented *inclination* steering behavior as simple means for considering the effects of ship motion on simulated passengers' movement. This first approach does not account for the dynamic nature of the phenomenon, thus ignoring motion accelerations. Ship-motion accelerations, however, are critical to the assessment of a person's balancing and/or sliding aboard ships and consequently to its capability of performing an assigned task. In this work, we are focusing on the exploitation of pre-computed ship motions and accelerations and we investigate the usage of the concepts of Motion-Induced Interruptions (MIIs) and tipping coefficients in modeling the effects of ship-motion accelerations on passengers.

Keywords: evacuation simulation, ship motions, motion-induced interruptions

1 Introduction

Virtual Environment for Life On Ships: V.E.L.O.S [1] is a multi-user Virtual Reality (VR) system that aims to support designers to assess (early in the design process) passenger and crew activities aboard a ship for both normal and hectic conditions of operations and to improve the ship design accordingly. The crowd modeling component of VELOS is build upon the steering behaviors technology and related enhancements that allow for consideration of passenger grouping and crew assistance behavior effects in ship-evacuation simulations [2].

Furthermore, VELOS provides communication interfaces enabling data import from computational packages, including *sea-keeping* and fire events modeling software. Pre-computed ship-motion history has been used in VELOS in conjunction with a kinematically-oriented *inclination* steering behavior as a first simple step for considering the effects of ship motion on simulated passengers' movement. Inclination behavior resembles in definition and effect the influence of a gravity field that would hinder agent motion accordingly. The aforementioned approach is a simple kinematic model that does not account for the dynamic nature of the phenomenon thus ignoring motion accelerations. Ship-motion accelerations, however, are critical to the assess-

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ment of a person's balancing and/or sliding aboard ships and consequently to its capability of performing an assigned task. In this work, we are focusing on the exploitation of pre-computed ship motion accelerations, readily available by the connected sea-keeping computational packages. Based on the works by Graham et al [3,4] and Crossland et al [5] we investigate the usage of the therein introduced concepts of *Motion-Induced Interruptions (MIIs)* and *tipping coefficients* towards modeling the effect of ship-motion accelerations on passengers aboard.

Specifically, in accordance to the calculated *tipping coefficients* and *MII*, we modify steering behaviors' weighting and/or behavior parameters to address the corresponding possibility of a motion interruption and degradation of assigned tasks' effectiveness. The assumption employed here is that a ship-motion-interrupted simple task, such as walking from point A to point B with MII incidents, could equivalently be modeled by appropriately modifying the steering-behavior blending leading to an analogous deduction of task effectiveness.

The rest of the paper is structured in three sections. Section 2 presents VELOS along with its major components and functionalities. Section 3 describes the ship-motion module of VELOS for both the simplified (kinematic) and dynamic approach. Finally, in Section 4, example involving typical passenger and crew movements aboard ship is presented. The simulated passengers' movement is examined with and without consideration of the ship motions effect.

2 The VELOS Environment

VELOS is based on *VRsystem* [6], a generic multi-user environment with a broad range of functionalities including geometric- and VR-modeling, as well as crowd microscopic modeling through a library of steering behaviors. Additionally, VRsystem can communicate with computational packages, e.g., sea-keeping software for improving the environment realism and taking into account ship-motion effect on passengers' movements. VELOS evacuation-specific functionality is greatly enhanced by the VR nature and client-server architecture provided by VRsystem, namely, the participation and real time interaction of remote multiple users in the form of avatars. These VRsystem-inherited features entail a very distinctive approach to evacuation analysis in VELOS, when compared with evacuation tools in pertinent literature [7,10]. The major key-points of the evacuation-specific functionality of VELOS are:

1. An integrated framework for both the *International-Maritime-Organization (IMO) simplified* and the *IMO-advanced* method of evacuation analysis[1]. Especially for the advanced method, we enhance IMO's approach by eliminating some important model omissions (e.g., ship motion, fire) and restrictive assumptions (e.g., simplistic crowd behaviors, full availability of escape arrangements).
2. Enrichment of the geometrical model of the ship with topological information for the improvement and better support of the path-planning procedure.

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3. Efficient communication through a number of interfaces that enable dynamic specification and handling of the required input data. These data comprise passenger/crew demographics and allocation, behavioral parameters, environmental conditions (fire, flooding) as well as ship motions.
4. Post-processing of the fundamental output (agent trajectories) for extracting evacuation-specific information, e.g., travel-time distribution, cumulative arrival time, passenger densities at specified areas.

2.1 Crowd Modeling

Steering behaviors technology is the basis of VELOS crowd modeling module. Individual agents are powered by an artificial intelligence structure, referred to in the pertinent literature as mind; see [14,15]. The mind utilizes a collection of simple kinematic behaviors, called steering behaviors, to ultimately compose agents' motion. Specifically, for each time frame, agents' velocity vector is computed by adding the previous velocity vector to the mind-calculated steering vector. This vector, in a simple approach, is a weighted average combination of the individual steering vectors provided by each associated steering behavior in agent's mind. The resulting steering vector is clipped to `max_force` parameter value and the resulting velocity vector is also clipped to another parameter value: `max_velocity`. This last parameter is generally different for each agent and follows the distributions of maximum speeds suggested by IMO for passenger and crew demographics (see [1],[2] for additional details).

Nearly twenty steering behaviors have been so far implemented within VELOS. These behaviors, based on the works of C.W. Reynolds [14] and R. Green [15], include: *Seek, Arrive, Wander, Separation, Cohere, Leader Follow, Obstacle Avoidance & Containment, Path-following, Pursuit, Flee, Evade, offset-{Seek, Flee, Pursuit, Evade, Arrive}.*

2.2 Ship Motions & Accelerations

VELOS provides several interfaces for the consideration of ship motions and accelerations. Specifically, there are modules that allow importing of pre-computed ship responses either in the frequency or time domain. Furthermore, there is also functionality for importing time histories of linear velocities and accelerations for selected points aboard a ship that are recorded with the aid of accelerometers. Thus, ship accelerations can be either estimated via numerical differentiation of ship motions or acquired from the experimental measurements.

Generally, ship motions comprise time histories of the displacements of a specific point P of ship (usually ship's center of flotation) as well as time histories of ship rotational motions (pitch, roll and yaw). Using numerical differentiation we can calculate linear velocity ($\boldsymbol{v}_p$) and acceleration ($\dot{\boldsymbol{v}}_p$) of point P and angular velocity ($\boldsymbol{\omega}_B$) and acceleration ($\dot{\boldsymbol{\omega}}_B$) of the ship. Then, using the following well-known relations from rigid-body kinematics we can calculate velocity and acceleration at every point Q on ship:

$$\boldsymbol{v}_q = \boldsymbol{v}_p + \boldsymbol{\omega}_B \times \boldsymbol{r}_{pq}, \quad (1)$$

$$\dot{\boldsymbol{v}}_q = \dot{\boldsymbol{v}}_p + \boldsymbol{\omega}_B \times \left(\boldsymbol{\omega}_B \times \boldsymbol{r}_{pq}\right) + \dot{\boldsymbol{\omega}}_B \times \boldsymbol{r}_{pq} \quad (2)$$

where, $\boldsymbol{r}_{pq}$ is the vector formed by **P** and **Q.**

3 Motion Effects Modeling

The effects of ship motions on passengers and crew aboard are modeled in two ways as it is presented in detail in the sequel. The first simplified approach is based on a kinematic modeling that utilizes the ship motions while the second approach takes into account the dynamic nature of the phenomenon and relies on the availability of ship accelerations

3.1 Inclination Behavior

Advanced evacuation analysis in VELOS is combining the availability of ship motion data with the so-called *Inclination* behavior that has been introduced, as a first layer, for considering the effect of ship motion on agent's movement. Pre-computed ship-motion history is imported in VELOS through a suitable series of interfaces. Inclination behavior resembles in definition and effect the influence of a gravity field that would hinder agent motion accordingly. Specifically, we consider a static global force-vector $\boldsymbol{g}$ normal to deck's plane in the upright position of the ship. If the deck deviates from its upright position (i.e., non zero heel, and/or trim, angles), the projection of $\boldsymbol{g}$ on it will obviously acquire a non-zero value $\boldsymbol{g_p}$, which forms *Inclination's steering vector* as follows: $\boldsymbol{f}_i = \lambda(\phi)\boldsymbol{g_p}$, where $\lambda(\phi)$ is an appropriate weight function depending on the angle ϕ formed between $\boldsymbol{g}$ and the normal to the deck plane. Inclination behavior is active when ϕ lies between two threshold angles: the lower threshold is used to discard plane motions with negligible effect on agent's motion, while values above the upper threshold lead to movement inability, as the limit of agent's balancing capabilities is surpassed. Threshold angles and the weight function $\lambda(\phi)$ are defined via experimental data; see, e.g., [11, 12].

3.2 Motion Induced Interruptions (MII)

During certain weather conditions, i.e., rough weather, walking and even more working in the ship becomes difficult and even the most experienced sailors will experience events where they must stop their activity, be it a specific task or merely standing, and take suitable measures to minimize the risk of injury, or more generally change their stance so that balance can be retained; these events are called, in pertinent literature, Motion-Induced Interruptions (MIIs). MIIs can be identified by considering the dynamic equations of motions of the person due to ship motion leading to the onset of loss-of-balance due to tipping or sliding.

Baitis et al [13] and Graham et al [3, 4] have proposed the following relations for the consideration of tips to port or starboard. Specifically, a tip to port will occur if:

$$T_{LATp} = \frac{1}{g}\left(\frac{1}{3}h\ddot{\eta}_4 - \ddot{D}_2 - g\eta_4 - \frac{l}{h}\ddot{D}_3\right) > \frac{l}{h}, \quad (3)$$

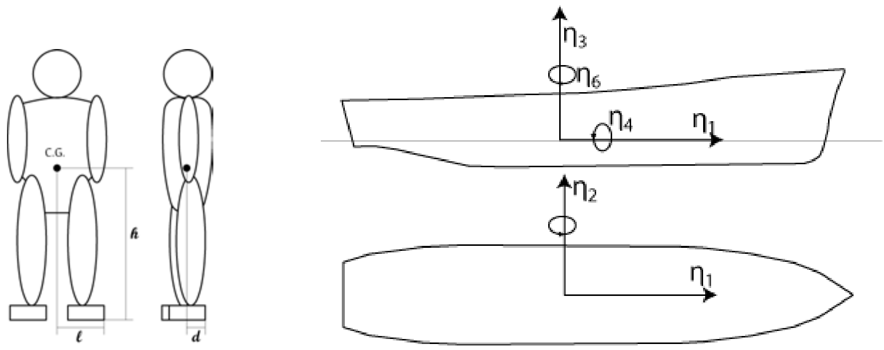
and a tip to starboard if:

$$T_{LATs} = -\frac{1}{g}\left(\frac{1}{3}h\ddot{\eta}_4 - \ddot{D}_2 - g\eta_4 + \frac{l}{h}\ddot{D}_3\right) > \frac{l}{h} \quad (4)$$

Similarly, the following tipping coefficients can be derived when considering tips to the aft or fore part of the ship:

$$T_{LONa} = \frac{1}{g}(\ddot{D}_1 + \frac{1}{3}h\ddot{\eta}_5 - \frac{d}{h}\ddot{D}_3) > \frac{d}{h}, \quad T_{LONf} = \frac{1}{g}(\ddot{D}_1 - \frac{1}{3}h\ddot{\eta}_5 - \frac{d}{h}\ddot{D}_3) > \frac{d}{h} \quad (5)$$

In the above equations, η_1 (surge), η_2 (sway), and η_3 (heave) stand for the translational while η_4 (roll), η_5 (pitch) and η_6 (yaw) stand for the rotational components of ship motion along the x-, y- and z- axis of the ship-coordinate system, respectively; see Fig. 1B. Furthermore, $\mathbf{D}$ = (D_1, D_2, D_3) = $(\eta_1, \eta_2, \eta_3) + (\eta_4, \eta_5, \eta_6) \times (x, y, z)$ denotes the displacement of point $P(x, y, z)$. Finally, symbols l, h and d denote the half-stance length, the vertical distance to person's center of gravity and half-shoe width respectively as shown in Fig.1A. Typical values for $\frac{l}{h}$ lie in the interval (0.20, 0.25) while for $\frac{d}{h}$ lie in (0.15, 0.17).



(A) (B)

Fig. 1. A) Person half-stance, C.G. and half-shoe width B) Ship Coordinate System

In the context of steering behaviors technology agent's velocity at each time frame is calculated as follows:

1. Compute steering vector $\boldsymbol{f} = \sum w_i \boldsymbol{f}_i$, where w_i are weights and $\boldsymbol{f_i}$ are the individual steering vectors from each simple behavior included in agent's mind.
2. New velocity is computed as:

$$\boldsymbol{v_{new}} = \begin{cases} (\boldsymbol{v}_{prev} + \boldsymbol{f}) \frac{\text{max\_velocity}}{\|v_{prev} + f\|} & if \ \|\boldsymbol{v}_{prev} + \boldsymbol{f}\| > \text{max\_velocity} \\ (\boldsymbol{v}_{prev} + \boldsymbol{f}) & \text{otherwise} \end{cases} \quad (6)$$

Taking into account the above discussion concerning tipping coefficients, the effect of ship motions on passenger movement is implemented in the following way:

1. Adjustment of `max_velocity` according to the following rule:

$$\text{max\_velocity} = \begin{cases} as\ is, & if\ T_{LAT} < 0.20 \\ \text{max\_velocity}\ (-20T_{LAT} + 5), & if\ 0.20 < T_{LAT} < 0.25 \\ 0, & if\ T_{LAT} > 0.25 \end{cases} \quad (7)$$

   That is, we have a linear reduction of `max_velocity` when $T_{LAT} > 0.20$ leading to a zero `max_velocity` when $T_{LAT} > 0.25$ (Motion Induced Interruption).
2. Adjustment of w_i weight values in computation of the steering vector. A typical scenario would include an increase of the wander behavior contribution and a decrease in Obstacle Avoidance and Separation contribution.
3. Adjustment of the parameters of each individual steering behavior. Such adjustments include a) the increase of the radius and position of the *wandering circle* for the wander behavior, which essentially leads to a wider range of possible turning angles and b) the reduction of the neighborhood radius of Separation behavior allowing passenger agents to come closer to each other. (For a description of Separation and Wander behaviors see [2, 15]).

4 Ship Motion Example

In this section, we examine passengers' movement on Deck 5 of a RO-RO passenger ship with and without ship motions' effect consideration. Specifically, we simulate the movement of two groups of passengers (20 persons) from points A and B respectively, to point C (see Fig.2) in still water, and at a sea state described by a wave spectrum with 4m significant wave height, 11 sec. peak period and 90^0 ship heading (beam seas). Ship responses were pre-computed and imported into VELOS using the SWAN seakeeping software package [16]. The cases examined have as follows:

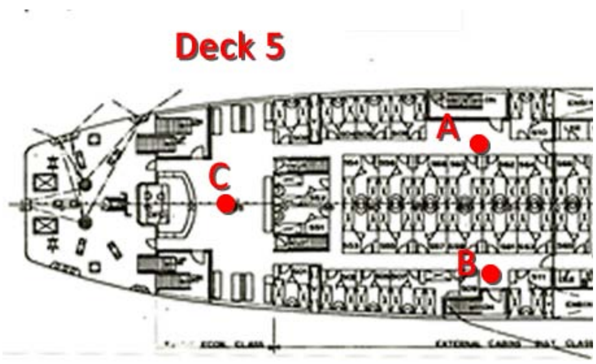


Fig. 2. Points A, B and C on Deck 5

- Test Case 1 (No waves): Still water
- Test Case 2 (Sea state as described above): Kinematic modeling of motion effects through inclination behavior
- Test Case 3 (Same sea state): Dynamic modeling using tipping coefficients implementation.

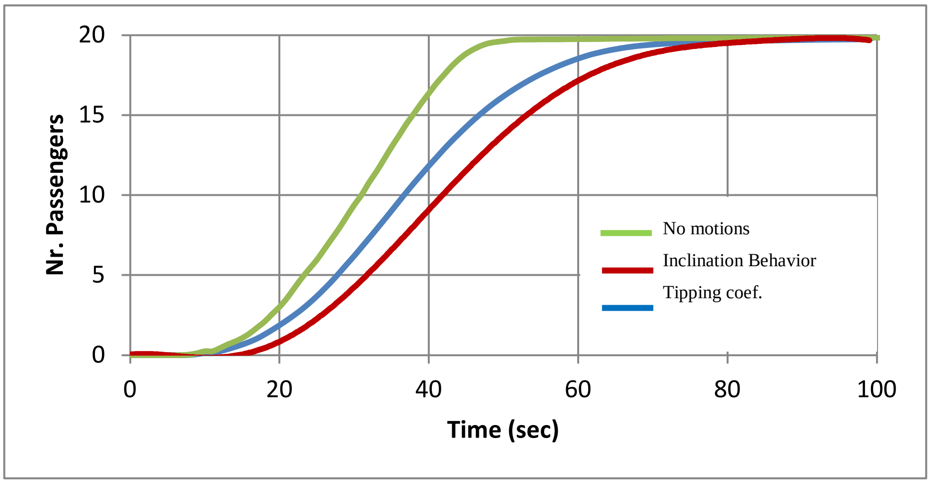


Fig. 3. Average cumulative arrival time for test cases 1, 2 and 3

Figure 3 depicts the average cumulative arrival time to point C for each of the three example cases. Each of the test cases has been simulated 500 times and the average travel times and arrival rates at point C have been collected. As it can easily be seen from this figure the time required for the prescribed passengers' movement is the least when we are in still water. The effect of the wavy sea state which induces ship motions and hinders passengers' movement is illustrated with the right-shifting of the remaining two curves. The total travel time needed for both inclination behavior and tipping coefficient modeling is about the same (~70secs) and considerably higher than the still water case (~50secs), where, obviously, no motion effect is considered. However the arrival rate (slope) for the tipping coefficient modeling is steeper than the slope of the curve corresponding to the kinematical approach.

5 Conclusions

We have demonstrated the usage of the two (kinematic and dynamic) ship motions' effect modeling approaches in a simple simulation example aboard a ship. The example results provide some first evidence that the followed modeling approaches are capable of capturing, at least qualitatively, the effect of ship motions on passengers and/or crew movements. A next step in our work will obviously involve the usage of the approaches in a full passenger ship evacuation scenario and the comparison of the simulation output with experimental results.

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