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# Toward a Human-like Sound Perception for Reactive Virtual Agents

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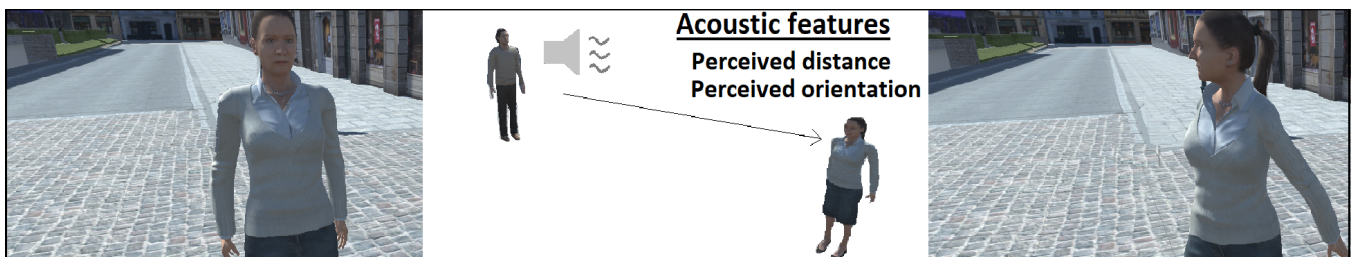


Figure 1: An Intelligent Virtual Agent having a reactive behaviour in the direction of a sound coming from the right

## ABSTRACT

Human social interactions rely on multisensory cues. In this regard, visual and auditory cues are paramount during the initiation of an interaction. In this preliminary work, we propose an approach to let Intelligent Virtual Agents (IVAs) simulating sound perception capabilities. Our model targets to control IVAs' reactive behaviour through their analysis of perceived other agents' emitted sounds. For that, we explored auditory features close to the human system.

## CCS CONCEPTS

• **Computing methodologies** → **Simulation environments; Motion processing; Procedural animation.**

## KEYWORDS

virtual agents, reactions, animation, sound perception, social interactions

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## 1 INTRODUCTION

As humans are social beings [16], social behaviours are paramount to any daily interaction. Moreover, humans expect other beings to have social behaviours with them, as shown in the literature for animals [1, 32], robots [17, 26], and virtual agents [5, 10].

In the field of virtual reality (VR), virtual agents are key to convey emotions and to allow for social interactions. They contribute to the social presence felt by users [29], along with their immersion [27] and engagement in VR [28]. However, to elicit such effects and to observe complex social behavioural responses [20], the design of virtual agents must overcome several issues. Yet, solutions are highly context-depend, for example for the visual appearance of agents, the appropriate quality level varies according to the quality of the environment and its purposes [31], e.g., when seeking naturalness in interactions, a photorealistic appearance elicits more realistic social responses [40]. Similarly, realistic motions, as well as speech quality, are key for VR users' perception of virtual agents [35].

Challenges remain to improve agents' believability [13], especially for social interactions, toward reactive behaviour modelling, contributing to making them Intelligent Virtual Agents (IVA). For this, Raimbaud et al. [30] proposed a visual perception approach, based on the analysis of how the motions of an agent are perceived from an other agent viewpoint. From the context and motion-depend features computed on the observed motions, reactions are triggered on the observer. However, no other kind of perception than the *visual* one was used in this study, despite humans daily use other types of cues to perceive an action before reacting to it.

Humans rely on crossmodal perceptions [15] that they process and balance to act and react, in real life and in VR [37], with real

humans and other agents (robots [36], virtual agents [24]). In many contexts, *sound* perception is paramount – usually combined with other sensory perceptions [14, 34], particularly to draw and maintain attention. In driving context, Wang et al. [38] found that drivers' performance improved through new usages of sound for advisory information (replacing visual cues), whereas Bellotti et al. [3] showed that its spatialisation improved driving, especially in case of low visibility. Similarly, it has been shown that spatialised sounds helped listeners to understand recorded music concerts, either regarding the music itself [2] or its social context [33]. Thus, in these contexts and based on human abilities to localise sources [8], spatialised sounds have succeeded in triggering oriented actions or reactions. This has also been observed on VR users [19]. Moreover, Huang et al. [22, 39] implemented a sound localisation approach to drive virtual agents' behaviours (e.g., chasing agents), relying on a sound field propagation model, used then to determine the source origin. In line with this, Chemistruck et al. [6] built another energy-wave propagation model, improved with masking and reverberation components. Finally, Cowan et al. [9] proposed to use a spatial graph and to estimate the sound propagation by computing its shortest path between the source and the receiver, from occlusions. However, these approaches did not intend to mimic the human receiving auditory system. Therefore, we propose in this paper a new model for sound reactive behaviours of virtual agents, from an egocentric viewpoint and inspired by human perception. Section 2 presents it, Section 3 a case study, and Section 4 its limitations and perspectives.

## 2 EGOCENTRIC SOUND PERCEPTION MODEL

We present here a new approach that contributes to the modelling of reactive behaviours – either between IVAs or with a VR user. It relies on a human-like egocentric perception of sounds, proposing thus a different perspective compared to previous work on agents in virtual environments [6, 9, 22, 39]. Fig. 2 displays our approach, which encompasses two steps: the computation of acoustic features on sounds as perceived from the receiver viewpoint, and a result synthesis step to induce reactive behaviours on the receiving agent.

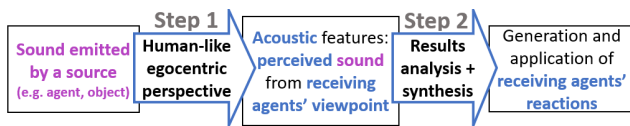


Figure 2: Sound perception model for IVA reactive behaviours

### 2.1 Acoustic features computation

Our first step consists in computing acoustic features from the receiver viewpoint, regardless of source sound characteristics and in a human-like perception way. We present three main features i) the perceived sound intensity, ii) the perceived distance, and iii) the perceived orientation; yet, our model is not limited to these ones.

In physical terms, the sound power  $P$  describes the behaviour of a sound source, independently from the distance, position and environment, whereas the sound intensity  $I$  refers to its power in a given area, thus measured at a specific position and representing the sound information perceived there. Therefore, capturing through a

listener the sound intensity at the receiver position is a paramount feature to understand the local perception of sound. In addition, the *perceived intensity* feature  $I$  can be used to compute a *perceived distance*  $r$  to the source, through the following formula [23], valid for source emission in spherical volumes and knowing its power  $P$ :

$$I = \frac{P}{4\pi r^2} \iff r = \sqrt{\frac{P}{4\pi I}}$$

It should be noted that, in a virtual environment and thus for numerical sounds, the computation of power and intensity depends on the induced volume of the different software layers (operating system, applications). A common approach is thus to use a reference power level value of the sound on a given volume, and to measure the intensity level at the virtual agent's position with the same volume, allowing then for the computation of the distance  $r$ .

The Interaural Time Difference (ITD) [25] refers to the time between the perception of a sound in the left ear and in the right ear, which is perceptible and used by humans for source localisation. The ITD can be expressed from the interaural distance ( $r_{int}$ ), the sound celerity  $c$  in the environment, and the  $\theta$  azimuth between the sound emitter direction and the axis passing through the ears, and therefore the *perceived orientation feature* can be computed from:

$$\Delta t = \frac{r_{int} \cdot (\theta + \sin(\theta))}{c}$$

### 2.2 Results synthesis and reactions generation

Mimicking the perception-action loop used by humans [21], we propose to generate and trigger reactions on the receiving agent [12] from the perceived acoustic features. This second step consists in synthesising the acoustic features results to drive realistic reaction behaviours on the IVA. We present here some possible analyses and syntheses from the acoustic features previously presented.

An analysis can be done on the perceived intensity by comparing it to a threshold value. For example, this one can be determined as the intensity of the ambient sound of the environment (background noise), or as a fixed minimum value for sounds to be considered as "triggering sources". In both cases, a reaction would be triggered on the IVA when the perceived intensity is higher to the threshold value. Thresholds on the perceived distance can be used similarly.

Another analysis can be performed on the perceived distance, along with the perceived orientation. The combined result can be used to determine a perceived position for the sound source from the receiver agent's viewpoint, and therefore to generate a reactive orientation motion in the direction of this computed position.

## 3 CASE STUDY: A CALL IN THE STREET

We present an illustrative case study to exhibit our approach: an IVA calls another IVA in the street – at a distance of 5m and at 90° on its right, to draw its attention by shouting. In this case, the perceived distance and perceived orientation acoustic features are computed in the first step of our model (results: 4.89m and 90°). From this, a perceived position is deduced, and a combination between torso, head and eye orientations is generated for a reactive behaviour of the receiving IVA toward the estimated sound source, realistically simulating a response to the calling of the other IVA. Fig. 1 shows this case study in a virtual environment where we implemented our model, here in Unity with sound spatialisation by SteamAudio.

## 4 LIMITATIONS AND FUTURE WORK

A first limitation, in the current development state of our model, is that we use sound power to compute the perceived distance feature. In real-life, humans use their ability to recognise the type of a sound, which they associate to a known power when they are familiar to it, to estimate then its distance [4, 11]. It would be interesting to use a similar approach in our model, e.g., through deep-learning approaches to recognise the type of the perceived sounds. Then, with our current implementation, results accuracy for the perceived azimuth orientation can vary depending on the IVAs' relative positions, e.g., with  $\pm 0-1^\circ$  accuracy for a  $90^\circ$  angle, and  $\pm 5-10^\circ$  for  $135^\circ$ . Even though human accuracy to localise sound can be up to 5 or  $10^\circ$  compared the real position in most conditions [18], our model could be improved by using more "human-like physiology" measures than only the ITD, e.g., interaural phase and level differences etc. This would also contribute to expand our human-like model with more features such as the perceived elevation angle.

As future work, our approach could be integrated in a more complex framework for IVAs' reactive behaviours, where multimodal egocentric perceptions would be used as humans do (e.g. combining our sound-based model with vision-based approaches [30]), as well as other types of approaches (e.g. deep-learning approaches where agents are trained to navigate to a sound source, as recently developed for robots [7]). Finally, we also aim to extend the use of our model to other case studies and contexts, notably with multiple "receiver agents", and also in VR with users that would interact with the virtual agents, and trigger reactive behaviours on them.

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