Ambient Surveillance by Probabilistic-Possibilistic Perception

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Abstract. *A method for quantifying ambient surveillance is presented, which is based on probabilistic-possibilistic perception. The human surveillance of a scene through observing camera sensed images on a monitor is modeled in three steps. First immersion of the observer is simulated by modeling perception of the scene from the camera locations using probabilistic perception approach. The perceptions are thereafter combined by means of probabilistic union, simulating simultaneous watching of the scene from multiple viewing positions. As third step the combined perceptions are converted to a possibility using triangular possibility density function. The latter step accounts for the fact that surveillance takes place via monitor depiction and not directly as perception of the actual physical scene. The method is described and demonstrated by means of an ambient surveillance application involving three cameras. The resulting possibility of perception is compared to the case of using two cameras, quantifying the added value of additional camera as to surveillance.*

Keywords. *Perception; possibility; ambient intelligence; surveillance.*

INTRODUCTION

Ambient Intelligence refers to electronic environments that are sensitive and responsive to the presence of people (Aarts and Encarnacao, 2006). Such electronic environments are called as ambient environment, referring to the surveillance of a physical ambience in the computer screen environment. Ambient Intelligence involves different fields including electrical engineering, computer science, industrial design, human machine interaction, and cognitive sciences. It stems from the combination of the three concepts ubiquitous computing, ubiquitous communication, and intelligent user friendly interfaces. It is considered to provide a vision of the information society, where greater user-friendliness, more efficient services support, user-empowerment, and support for human interactions is aimed for. In this vision people are surrounded by intelligent intuitive interfaces that are embedded in different kinds of objects yielding an environment that is capable of recognizing and responding to the presence of different individuals in a seamless, unobtrusive or invisible way (Ducatel et al., 2001). The European Commission's Information Society Technologies Advisory Group (ISTAG) considers Ambient Intelligence an important concept, as they predict that the concept will be applied to everyday objects such as furniture, clothes, vehicles, roads and smart materials. According to ISTAG, Ambient Intelligence implies machine awareness of the specific characteristics of human presence and personalities, taking care of
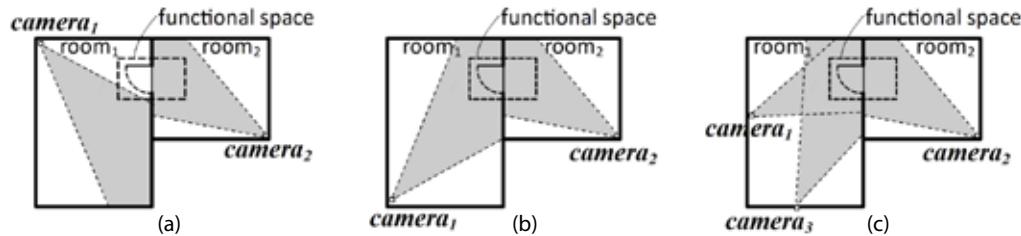
needs and being capable of responding intelligently to spoken or gestured indications of desire (Weyrich, 1999). Benefits in some practical applications have been reported, see e.g. Augusto and Shapiro (2007), Streiz et al. (2007), Ramos et al. (2008), Augusto and Nugent (2006). Examples of application areas are personal assistance by mobile devices (Richard and Yamada, 2007), clothing (Boronowsky et al., 2006), entertainment (Saini et al., 2005; Dornbush et al., 2007), office and meetings rooms (Waibel et al., 2010), and home environments (Aarts and Diederiks, 2007; Nakashima, 2007). The benefits in the applications concern enhanced security, and utility. Concerning security, an issue of common relevance is surveillance of objects in buildings, e.g. see (Takemura and Ishiguro, 2010). The objects may concern building elements such as doors, hallways, etc., as well as valuable articles. For instance, in an environment the monitoring of people passing through the doors may be of relevance for security purposes, so that the locations where surveillance cameras are suitably placed, and the number of cameras used to supervise the environment, are important issues to consider. This may be relevant both during the design of an ambient environment, as well as during the assessment of the surveillance provided for an existing environment. In an existing work this issue is addressed by verifying if a functional space of a door is fully covered by supervision cameras (Bhatt et al., 2009), which is a requirement to guard the traffic between the rooms. This is seen in a plan view in Figure 1a, where the door and its functional space, which is shown by a rectangle, are not fully covered by the fields of view of two cameras. This yields requirement inconsistency. Figure 1b shows a situation where the door and its functional space are entirely within the fields of view of the two cameras, thereby complying with the requirement. In Figure 1c three cameras are used, and the consistency requirement is also fulfilled.

In an ambient intelligent system, human supervision may be important in case continuous in-situ monitoring of scenes is demanded for instant human intervention. In such a case, the functional space shown in Figure 1 is to be supervised by human through monitor watching. Here the human perception plays an important role. The actual scene is surveyed by the cameras, and at this stage human perception is not in the play. However, the image of the functional space is propagated to a screen, and then the human perception via the screen becomes an issue of assessment. Such assessments should be quantified to understand the difference among the probable camera positions, or among cases where different number of cameras are used. It is emphasized that two, three, or more cameras may be used to cover the functional space entirely, as exemplified in Figure 1b and 1c, so that compliance with the consistency condition described above can be achieved in several ways that are not equivalent with respect to surveillance. As the human should realize the presence of objects and events in his mind, which is a complex brain process involving uncertainty, quantitative assessment of the human perception in the ambient environment surveillance case becomes desirable and is challenging to accomplish. Comparing the situations in Figure 1b and 1c, qualitatively three cameras in Figure 1c are favorable with respect to the human perception of the functional space, providing more visual infor-

mation about the object to the human. Following the approach of existing works, such as Bhatt et al (2009), surveillance in Figure 1b and 1c is considered to be the same, as requirement consistency is treated as a binary statement. Binary verification of the requirement compliance is giving some indication about the effectiveness of the camera surveillance. However, this may be not enough for the case of human supervision, which is based on human perception. Based on this view, the present work intends to make some steps forward along this line, providing measured assessment about the quality of surveillance of an ambient environment based on perception modeling. Measured assessment is desirable in particular when optimal solutions are sought during design of an environment, for instance with respect to maximizing surveillance by optimal placement and orientation of sensors, or minimizing the number of cameras while sufficient surveillance is provided. We note that in this work we assume that there is no automated camera system for object recognition involved, although even in that case, differentiation among alternative camera utilizations, in order to determine the effectiveness of the machine recognition, still remains an issue.

The organization of the paper is as follows. The *methodology* section describes the treatment of the probabilistic and possibilistic aspects of the surveillance. The *computer experiment* section describes an example application of the method for an ambient environment, and the section is followed by *conclusions*.

METHODOLOGY

This research aims to make assessment about the quality of human surveillance of an object based on camera sensed information. When a human views a camera sensed scene on a screen, in order to give meaningful interpretation to the scene he infers the information about the camera position and orientation from the scene, without having been explicitly informed about these. This process of assuming of a camera position by human is called immersion. To model this early stage of the ambient environment

analysis by human, probability theoretic computations are used to simulate perception of objects by a human, who is immersed in the scene at the camera viewpoints.

Probabilistic Perception Revisited

Due to the complexity of brain processes underlying perception, perception is to be modeled as a probabilistic event. That is, there is a chance to see an object, meaning the presence of the object is realized in mind, which implies a chance of overlooking the object, too. We can term this as the uncertainty of human vision (Rensink et al., 1997; Bittermann and Ciftcioglu, 2008). For a single unbiased observer this uncertainty is quantified as described in Ciftcioglu et al (2006b), Bittermann and Ciftcioglu (2008). Consider the basic geometry as shown in Figure 2a. P represents an observer's point, where he is viewing an object. We consider a *perception plane* located at distance l_o from the observer, and a *scope of vision plane* orthogonal to the perception plane, having the observer's point and the object in it. The intersection of the perception plane and the scope of vision plane is the *y*-axis. A line perpendicular to the perception plane, passing from the point P, is the *x*-axis. The observer has a visual scope in the scope of vision plane, defined by the angle $\theta_s = \pi/2$, which is termed as vision angle. He is viewing the object that subtends the angle $\theta_b - \theta_a$. An unbiased observer is modeled, i.e. he has no preference for any direction within the visual scope. This means the probability density function (pdf) with respect to θ is given by $f_\theta(\theta) = 1/\theta_s$, as seen in Figure 2b upper. As the object subtends the perception angle $\theta_b - \theta_a$, it has an as-

sociated perception $P = \int_{\theta_a}^{\theta_b} f_\theta(\theta)\,d\theta = (\theta_b - \theta_a)/\theta_s$, shown by the gray shaded area in Figure 2b upper. P quantifies the probability the object is mentally realized by the observer. The perception can be computed along the *y*-axis in Figure 2a by radially projecting the object from P on the *y*-axis. It yields a line segment, spanning y_a and y_b, as seen in the figure. The uniform pdf with respect to the vision angle θ is given by $f_\theta(\theta) = 1/(\pi/2)$ and corresponds to the follow-
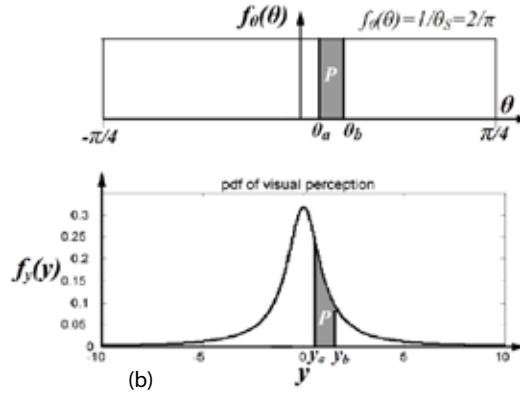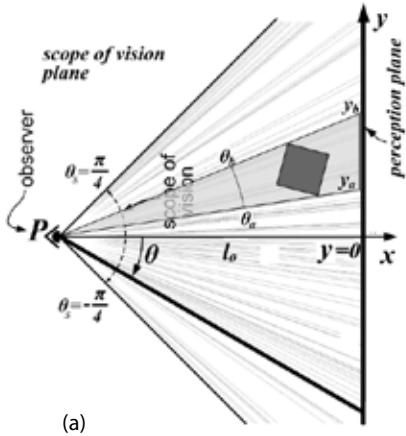
(a)

(b)

ing probability density with respect to y (Bittermann and Ciftcioglu, 2008)

$$f_y(y) = \frac{2}{\pi} \frac{l_o}{(l_o^2 + y^2)} \quad (-l_o \leq y \leq l_o)$$

(1)

The plot of (1) for $l_o=2$ is seen in Figure 2b lower. The perception is computed by

$$P = \int_{ya}^{yb} f_y(y)\, dy$$

(2)

and the result is shown by the gray shaded area in the figure. It is emphasized that the sizes of the gray shaded areas in Figure 2b upper and 2b lower are the same. We note that for the perception of a three dimensional object both vision angle and perception angle become respective solid angles.
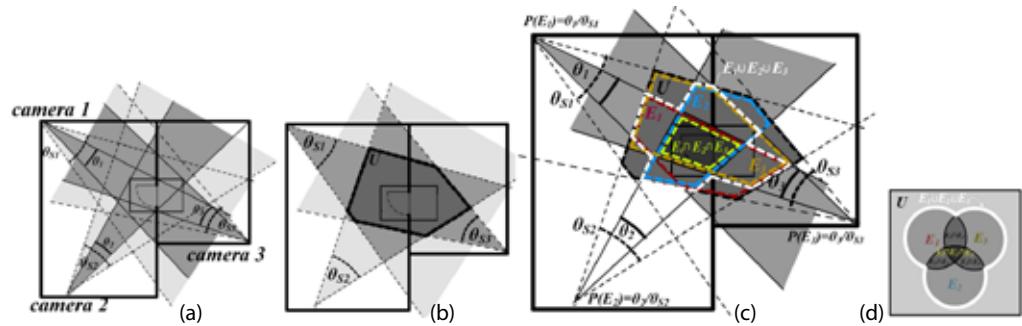
Union of Perception Events

We emphasize that for the surveillance of the ambient environment being considered, the consistency requirement mentioned above stipulates that the functional space should be entirely encompassed by multiple cameras' fields of view. This means a human observing the scene will obtain the information from multiple cameras at the same time. In this respect we consider the case shown in Figure 1, where a single camera is not sufficient to comply with the consistency requirement, and in this study we consider the perceptions by means of three cameras, denoted *camera 1*, *camera 2* and *camera 3* in

Figure 3. The scene subject to investigation is shown in Figure 3a, presenting a plan view of two rooms connected by a door and an associated functional space shown by a rectangular box around the door. The functional space is subject to surveillance via the three cameras, where the visible portions of this space respectively subtend the angles θ_1, θ_2, and θ_3 as indicated by the dark shaded areas in the figure. The dashed lines in the figure indicate the boundaries of the cameras' fields of view, where their associated angles θ_{S1}, θ_{S2}, θ_{S3} are taken to be the same in this example. The intersection among the three camera scopes form a universe of discourse for the surveillance events as shown in Figure 3b by means of bold dashed lines. We define the following three perception events within this universe as seen in Figure 3c. The event a human observer, who is immersed at *camera 1*, becomes aware of the functional space that is at the same time within the scopes of *camera 2* and *camera 3*, is denoted by event E_1. Conversely, the perception event from *camera 2* that is at the same time within the fields of view of *camera 1* and *camera 3* is denoted by E_2. In the same way, the perception event from *camera 3* that is at the same time within the fields of view of *camera 1* and *camera 2* is denoted by E_3. The regions in the scene corresponding to the events are shown in Figure 3c, where the space belonging to E_1 is delimited by

means of red dashed lines, for E_2 by means of blue dashed lines, and for E_3 by means of orange dashed lines. The probability of the perception events is obtained by $P(E_1)=\theta_1/\theta_{S1}$, $P(E_2)=\theta_2/\theta_{S2}$, and $P(E_3)=\theta_3/\theta_{S3}$. It is to note that E_1, E_2, and E_3 are independent events. With respect to ambient surveillance assessment being aimed for in this work, the event subject to computation is the union of the perception events $P_U=E_1 \cup E_2 \cup E_3$. The union refers the event that the observer becomes aware of the functional space either via immersion at *camera 1, camera 2, camera 3* or via combinations among them at the same time, while the consistency condition, namely that the event is to take place within all cameras' fields of view, is fulfilled at the same time as boundary condition. The region of space in the scene that corresponds to $E_1 \cup E_2 \cup E_3$ is delimited by the white dashed line in Figure 3c. The region of space in the scene that corresponds to $E_1 \cap E_2 \cap E_3$ is visualized in the same figure by means of a yellow dashed line. Figure 3d shows a Venn diagram corresponding to the perception events in Figure 3c.

The regions corresponding to the universe of discourse and encompassing the perception events are shown in 3D renderings in Figure 4. Figure 4a shows the fields of view of the cameras from top view in red color, as well as the cones encompassing the respective perception events E_1, E_2, and E_3 in yellow color. The same regions are shown in Figure 4b from a perspective view. Figure 4c shows the universe of discourse from top view and Figure 4d from a perspective view. Figure 4e shows the region cor-

responding to $E_1 \cap E_2 \cap E_3$ from plan view, and Figure 4f shows the same region from a perspective view. The probabilities $P(E_1)$, $P(E_2)$, and $P(E_3)$ are obtained by similar computations as given by (2) but for three dimensional space, where θ becomes solid angle Ω.

Converting the Probability into Possibility
It is emphasized that the computations above model the perception of observers, who are viewing the functional space being present at all three camera positions. However, the scene is actually viewed on a monitor screen and not directly from locations in the physical environment. That is, no actual object is being perceived in the ambient environment case, but a visual representation of the scene on a screen is being perceived. This yields the *immersion* phenomenon, which we can also term as virtual perception. In the ambient environment case, instead of perception alone an assessment of the perception is to be carried out, and this assessment should be expressed in possibilistic terms, namely as possibility of perception. This means the probability quantifying the perception of the object by the observer should be converted to a possibility of perception. This is shown in Figure 5. Figure 5a shows the perceptions of the functional space from the three cameras. The probability density functions $f_\theta(\theta)$ are integrated along angle dimension θ, yielding the perceptions $P(E_1)$, $P(E_2)$, and $P(E_3)$. It is to note that each of the three integrals have their center points at $\theta=0$ as seen in the figures. This is due to the surveillance purpose, where the cameras are oriented
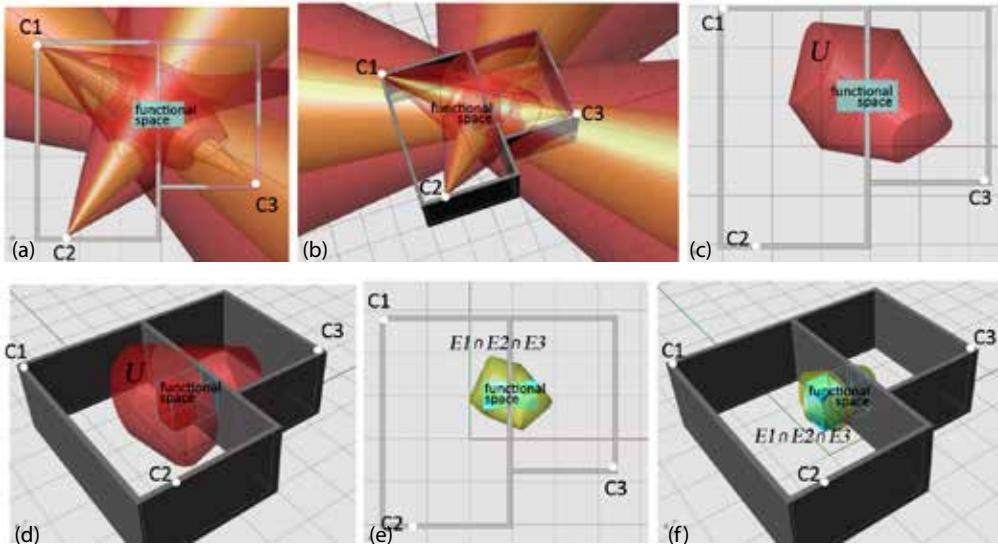
in such a way that the object subject to perception is located at the center of the respective fields of view of the cameras. The probability of the union of the perception events $P(E_1 \cup E_2 \cup E_3)$ is shown by the hatched area in Figure 5b. Being an integral of the uniform pdf $f_\theta(\theta)=1/\theta_s$, $P(E_1 \cup E_2 \cup E_3)$ corresponds to an angle domain θ', as seen in the figure. It is noted that $P(E_1 \cup E_2 \cup E_3)$ is also centered at $\theta=0$ being the reference point of the perception computation in the scene as result of the immersion phenomenon. The pdf has a possibilistic density counterpart, namely a triangular possibility density function as seen in the figure. It is noted that the possibility density is maximum at the place that corresponds to the expected value of the uniform probabilistic density with respect to θ, namely $\theta=0$. Therefore, next to being the reference point for the perception computation sim-

ulating the immersion, the point $\theta=0$ also represents a reference point for perception possibility computation on the monitor, as zero refers to the center of the fields of views of the cameras, i.e. center of monitoring screen. For the possibility assessment, the possibility density is subject to integration over the angle domain θ', where the integration starts from $\theta=0$, yielding the dark gray shaded area in Figure 5b, the size of which quantifies the possibility of perception. It is emphasized that the integration starts from zero, i.e. in the middle of the screen, as to human perception, the possibility of perception is assessed starting from the middle of the screen. θ' starts from zero and maximally extends covering the interval $-\theta_s/2$ and $+\theta_s/2$, so that its maximum value becomes θ_s. Figure 5c shows a sketch of the relationship between possibility of perception versus the
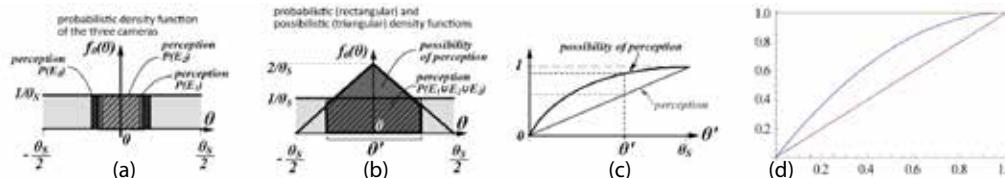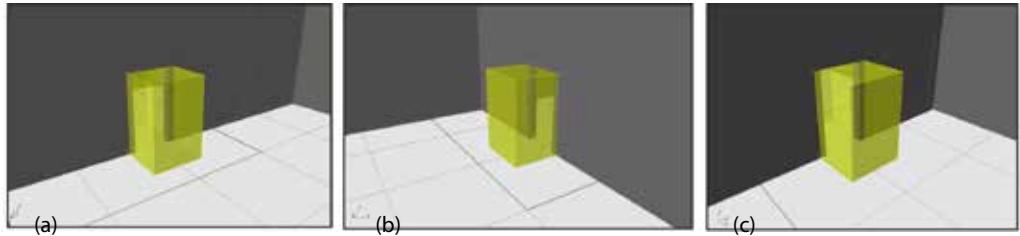
corresponding union of perceptions, and Figure 5d shows a plot of the same relationship. From Figures 5c and 5d it is seen that for a certain perception *P*, there is always a perception possibility having a greater value than *P*. As the perception is increasing, the associated possibility is also increasing in a non-linear way. In this treatment, obviously there is no possibility consideration if perception is not occurring. This means a triangular possibility density cannot be constructed without having referred to a probability density associated with perception. Such probability density is known to be attention (Ciftcioglu et al., 2006b). It is noted that shape of the function shown in Figure 5c is independent of the size of the scope θ_s.

The possibility density function defined as a triangular fuzzy set shown in Figure 5b is the counterpart of the probability density function with respect to perception along the *y*-axis shown in Figure 2b lower. The form is precisely represented by the Cauchy function given by (1) that simulates the human perception in the scene as result of the immersion process. Both functions, namely triangular possibility density function and Cauchy probability density function, have a maximum at the respective reference starting points. This is confirmed by the common vision experience, that an observer is more aware of an object positioned in front of him, compared to a similar object that is located at some lateral distance from the former object. This is because the observer will remember more details of the former compared to the latter. It is noted that the shape of the monitor screen is not relevant to this computation.

COMPUTER EXPERIMENT

Based on the considerations above a computer experiment is carried out, where the possibility of perception is obtained for the scene shown in Figure 4 with the camera positions as indicated in the Figure. It is noted that the cameras are located at the ceilings of the rooms at the same height, and they are oriented in such a way that the central line of the cameras' fields of view are directed towards the center points of the respective visible portion of the functional space. The camera pictures of the scene taken from the three positions are shown respectively in Figures 6a, 6b, and 6c.

In the experiment, the unbiased visual attention given by the probability density per unit solid vision angle Ω given by $f_\Omega(\Omega)=1/\Omega_s$ and $\Omega_s=\pi$ *sr* is approximated by means of probabilistic ray tracing, in order to deal with geometric complexity of environment. In this treatment rays are sent in random directions from camera position, and the intersections with environmental objects are analyzed. The ray directions are generated in such a way that $f_\Omega(\Omega)=1/\Omega_s$ is approximately fulfilled, which is accomplished by using multiple Gaussian pdf as described in Ciftcioglu et al (2006a). Figure 7 shows the rays sent to simulate the perceptions via the three cameras. Figure 7a shows the rays that simulate the unbiased vision within the scope defined by the cameras' fields of view, from a plan view. These are termed as *vision rays*. The same rays are shown in Figure 7b from a perspective view. It is noted that in order to display individual rays, in the figure merely 200 rays per camera position are shown, although in the experiment 2000 rays are used for accuracy of the results. Figure 7c shows those rays among the vision rays that inter-
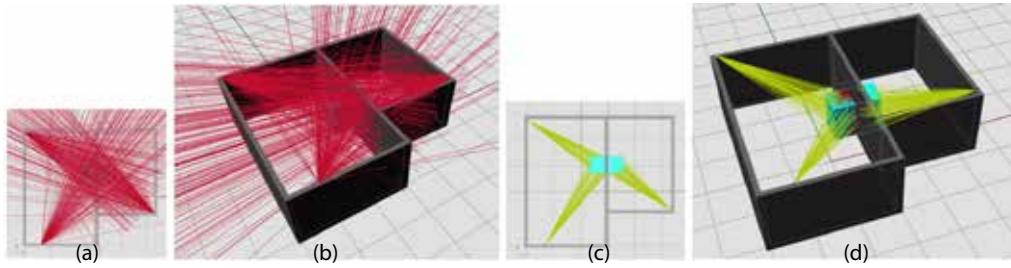
sect the functional space in a plan view, and these are termed as perception rays as they simulate the perception events E_1, E_2, and E_3. The same perception rays are shown in Figure 7d in a perspective view. The perception event $P(E)$ is obtained by $P(E)=n_p/n_v$, where n_p denotes the number of perception rays, and n_v the number of vision rays.

The results from the experiment are $P(E_1)=.246$; $P(E_2)=.207$; $P(E_3)=.310$, so that $P(E_1\cup E_2\cup E_3)=.588$, yielding *possibility of perception* as $p_p=.830$. This quantifies the possibility of perceiving an event at the functional space of the door based on the camera positions considered. It is interesting to investigate what the difference in perception possibility is in case two cameras are used instead of three. Considering the case *camera 1* is not used, then $P(E_2\cup E_3)=.453$, yielding the perception possibility as $p_p=.701$. In case *camera 2* is not used, then $P(E_1\cup E_3)=.480$ yielding perception possibility as $p_p=.729$; and for *camera 3* being not used $P(E_1\cup E_2)=.402$, so that the possibility becomes $p_p=.642$. Thus, compared to using two cameras, use of three cameras increases the possibility of perception by *18.4%, 13.9%,* and *29.3%* respectively for the three cases. It is also interesting to consider using only one camera compared to using three cameras. Using *camera 1* exclusively, the perception possibility is $p_p=.431$ so that the three cameras entail an increase of *93%;* using *camera 2* exclusively the possibility is $p_p=0.371$ implying an increase for the three cameras of *124%*; and in case exclusively camera 3 is used the perception possibility is $p_p=.524$ implying an increase of *58%* for the case of using the three cameras. This information is essential in determining the surveillance level of environ-

ments, and in particular provides information on the remaining surveillance in the case of a camera failure, which provides an indication of the robustness of a surveillance situation.

CONCLUSIONS

A probabilistic-possibilistic approach that models surveillance of a scene by human via three cameras is described. The first stage in camera based human surveillance is the immersion phenomenon, and this is modeled in the presented work by means of perception computations that are probabilistic in nature. These computations reflect the fact that remembrance of visual information processed by human vision system is not certain, i.e. it is subject to probabilistic considerations. The second stage of the surveillance is conversion of the perception into possibility. The possibilistic treatment accounts for the fact that the observation event does not concern perception of an object from an actual location in space, but perception of a camera sensed image of the object on a monitor. This way perception is assessed in the form of a fuzzy statement. In the same way as probability is due to integration of a probability density over some physical domain, so that it is associated to an event, possibility is computed by means of integration of an associated possibility density function belonging to the same domain. The domain in the present case is vision angle. The computer experiments presented in this paper confirm the qualitative statement, that the number of cameras influences the possibility of perception. The probabilistic-possibilistic treatment described in this paper uniquely quantifies this possibility, providing

precision assessment of surveillance of ambient environments. This implies that through the novel approach, subtle differences among surveillance situations are distinguished, allowing for more conscious decision making. This may have important place in diverse applications, such as domestic healthcare, safety and security of buildings and cities, applying to both, existing situations, as well as during design of new environments. It is interesting to note that different stakeholders may use the method for different purposes, such as verifying if surveillance is sufficient, or verifying that it is not excessive, for instance for the sake of privacy of users.

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