Ambient Environment Analysis by means of Perception

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Abstract. Analysis of an ambient environment by means of perception is described. The surveillance of an object by human, who watches a scene via a monitor that shows camera sensed information, is investigated. Although the camera sensing process is a deterministic process, human perception of a scene via camera sensed information is a probabilistic process, i.e. the observer may overlook information about the scene, while this may be unlikely. The human surveillance based on camera sensed information is modelled in the present work by means of probabilistic computations. Thereafter conversion of the probability into possibility is carried out, quantifying the perception possibility attached to an object, thereby providing an assessment of the surveillance. Thereafter the suitability among alternative camera positions as to surveillance of an ambient environment is subjected to precise comparison. The method is described and applied in two computer experiments, measuring the surveillance of an ambient environment.

1. Introduction

The theme of Ambient Intelligence is getting growing attention due to its importance in some practical applications, e.g. see Augusto and Shapiro (2007), Streiz, Kameas et al. (2007), Ramos, Augusto et al. (2008), Augusto and Nugent (2006), Aarts and Diederiks (2007), Takemura and Ishiguro (2010). In this context perhaps security and utilitarian purposes take the important place. Ambient Intelligence refers to electronic environments that are sensitive and responsive to the presence of people, and it can be implemented in various ways, satisfying the requirements of the application. Such electronic environments are called as ambient environment, referring to the surveillance of a physical ambience through the environment represented by the computer screen. For instance, in an environment the monitoring of people passing through the doors may be of relevance for security purposes. Thus the locations, where surveillance cameras are suitably placed to survey the ambience, are an important issue 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. From this viewpoint the issue is addressed by Bhatt, Dylla et al. (2009), verifying if a functional space of a door is fully covered by supervision cameras, 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, which are shown by the grey shaded areas. Figure 1b

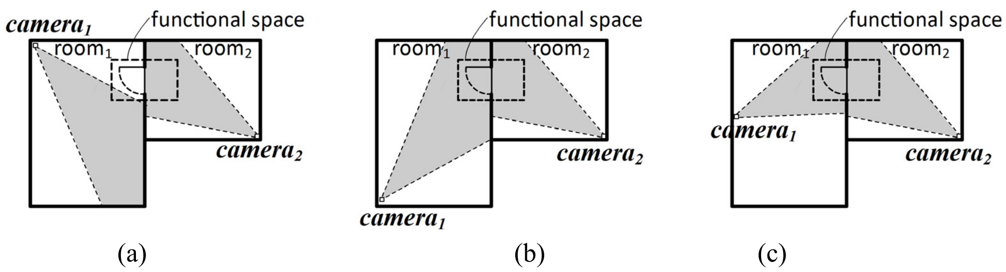


Figure 1: Figure taken from Bhatt, Dylla et al. (2009): A door's functional space is not fully covered by both cameras' fields of view (a); the space is fully covered the fields of view (b); an alternative camera positioning covering the space fully by the fields of view (c)

shows a situation where the door and its functional space are entirely within the fields of view of the cameras, thereby complying with the requirement. This verification of the requirement compliance is giving some indication on the validity of camera positions. However, this may be not enough for the case of human supervision, which is based on human perception. In an ambient intelligent system, emulated 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, where 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 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 precision positioning of the probable camera positions, to settle their proper placement. Two cameras may be positioned at various locations and directed in such a way that they both cover the functional space entirely, as shown in figures 1b and 1c, exemplifying compliance with the requirement described above. The compliance can be achieved in several ways. In the work by Bhatt, Dylla et al. (2009) it is assumed that all camera positions are equally valid with respect to the functional space surveillance, as long as an object is entirely within the field of view of the cameras, and human surveillance issues are excluded. However, it may be relevant to distinguish among different camera positions with respect to human perception. Comparing the situations in figure 1b and 1c, it is clear that with respect to the human perception of the functional space, qualitatively the positions of the cameras in figure 1c are favorable, as in this case $camera_1$ is nearer to the functional space providing more visual information about the object to the human. From the camera sensed information the human should realize the presence of objects and events in his mind, so that quantitative assessment of the human perception in the ambient environment surveillance case becomes desirable and challenging to accomplish. 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, i.e. taking the human factor into account. It is to note that in this work we assume that there is no automated camera system for object recognition involved. However, even in that case, differentiation among alternative camera positions, in order to determine the effectiveness of the machine recognition, still remains an issue.

The organization of the paper is as follows. Section two describes the methodology used, which models the human perception and its role in surveillance of ambient environments. Section three describes an application of the method, quantitatively analyzing the surveillance of an example environment. This is followed by conclusions.

2. 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 visual information, without having been otherwise informed about these. This process of assuming of a camera position by human is called immersion. Perception of objects by a human who is immersed in the scene at the camera viewpoints is modeled using probability theoretic computations.

2.1 Perception Revisited

The perception of an object by a single, unbiased human observer is quantified as described by the probabilistic approach in Ciftcioglu, Bittermann et al. (2006), Bittermann and

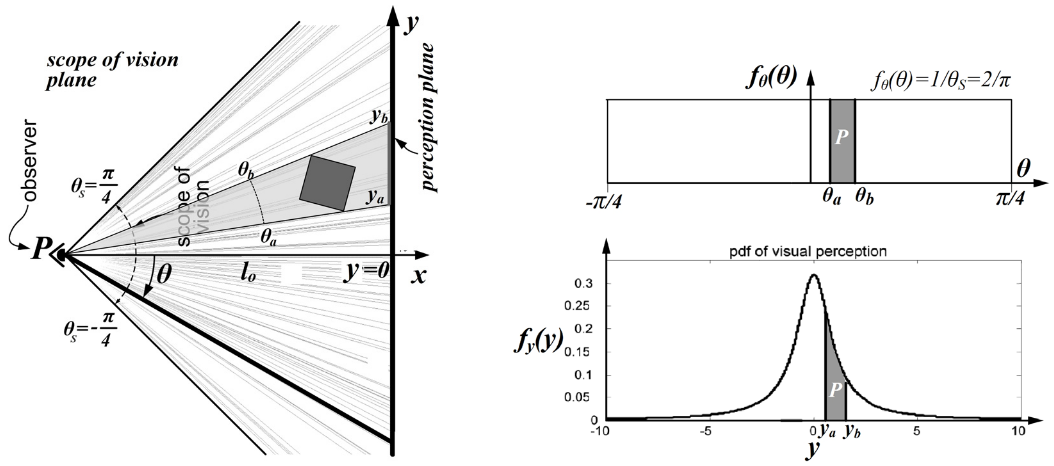
Ciftcioglu (2008). It is to note that the probabilistic approach conforms to the common vision experience that objects may be overlooked, although they are within an observer's visual scope, which is due to the complexity of the brain processes involved in human vision. Consider the basic geometry as 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 these planes is the *y*-axis. A line perpendicular to the perception plane, passing from the point *P,* is the *x*-axis. We consider the object resides in the scope of vision plane. The observer has a visual scope defined by the angle $\theta_S=\pi/2,$ which is termed as vision angle. He is viewing the object that subtends the angle θ_b-θ_a, which is termed as perception angle. 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 θ_b-$\theta_{a},$ it has an associated perception $P=\int_{\theta a}^{\theta b} f_o(\theta)\,d\theta=(\theta_b-\theta_a)/\theta_s$, 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. Then 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 following probability density with respect to *y* (Bittermann and Ciftcioglu 2008)

$$f_y(y)=\frac{2}{\pi}\frac{l_o}{(l_o^{\,2}+y^2)} \quad (-l_o \le y \le l_o) \tag{1}$$

The sketch of (1) is seen in figure 2b lower. The perception is computed by

$$P=\int_{ya}^{yb} f_y(y)\,dy \tag{2}$$

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. For the perception of a three dimensional object both vision angle and perception angle become respective solid angles.

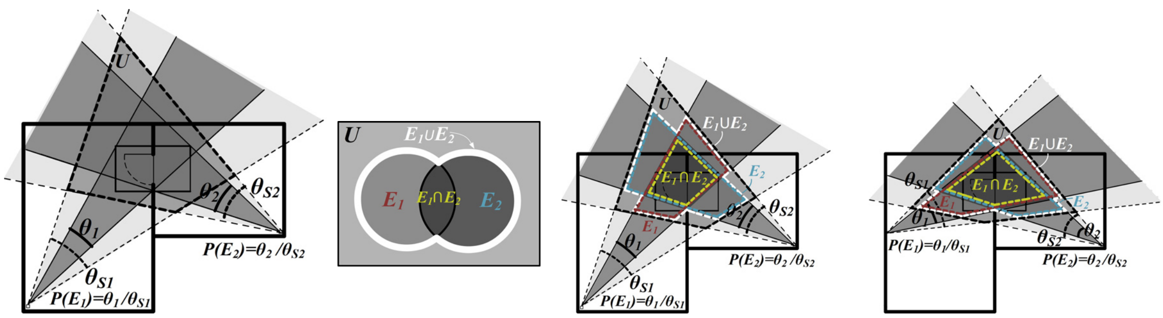


(a) (b)

Figure 2: An object projected on the perception plane and perceived from *P* (a); sketch of the probability density function (pdf) characterizing perception with respect to θ (b upper); pdf characterizing perception with respect to the *y* direction for $l_o=2$ (b lower)

2.2 Intelligent Ambient Environment and Perception

We emphasize that for the surveillance of the ambient environment being considered, the consistency requirement mentioned in the introduction stipulates that the functional space should be encompassed by both cameras' fields of view. This means a human observing the scene will obtain the information from both 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, so that we consider the perceptions by means of two cameras, $camera_1$ and $camera_2$. In accordance with the consistency requirement a universe of discourse is defined, which encompasses all events that occur within the intersection of both cameras' fields of view. The universe of discourse is denoted by *U,* and the region of space in the scene that corresponds to *U* is shown in figure 3a by means of bold black dashed lines. Figure 3a shows a plan view of the scene being investigated, where the fields of view of the cameras are delimited by the angles θ_{S1} and θ_{S2}. The perception of an object subtending the angle θ_1 from $camera_1$ by an unbiased human observer, who is immersed at the camera, is characterized by the probability density $f_{\theta1}(\theta_1)=1/\theta_{S1}$. In the same way, for an object subtending the angle θ_2 from $camera_2$ the probability density $f_{\theta2}(\theta_2)=1/\theta_{S2}$. From the figure we note that the angles subtended by the functional space from the respective cameras are denoted by θ_1 and θ_2. It is to note that in the determination of θ_1 and θ_2 , the geometry of the rooms are used, and after that we do not consider any geometry or other vision limitations in the union of perceptions computations. The universe of discourse in figure 3a is also shown in a Venn diagram in figure 3b.



(a) (b) (c) (d)

Figure 3: Perception via two cameras with the perception angles θ_1 and θ_2 (a); Venn diagram of the associated perception events (b); visualization of the union of the perception events for a certain position of $camera_1$ (c); for an alternative position of $camera_1$ (d)

We define the following two perception events within the universe of discourse. 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 scope of $camera_2$, is denoted by event E_1. Conversely, the perception event from $camera_2$ of the functional space that is at the same time within the field of $camera_1$ is denoted by E_2. The spaces corresponding to the events are shown in figure 3c and 3d, where the space belonging to E_1 is delimited by means of red dashed lines, and for E_2 by means of blue dashed lines. The probability of the perception events is obtained by $P(E_1)=\theta_1/\theta_{S1}$ and $P(E_2)=\theta_2/\theta_{S2}$. With respect to ambient surveillance assessment being aimed for in this work, the event subject to computation is the union of the perception events $E_1 \cup E_2$. The union refers the event that the observer becomes aware of the functional space either via immersion at $camera_1$ or $camera_2$, or via both at the same time, while the consistency condition is fulfilled at the same time as boundary condition, namely that the event is to take place within both camera fields.

The union of the events is seen in the Venn diagram in figure 3b by means of a white line. The region of space in the scene that corresponds to $E_1 \cup E_2$ is delimited by the white dashed lines in figures 3c and 3d. The probability of the union of events is given by $P(E_1 \cup E_2)=P(E_1)+P(E_2)-P(E_1 \cap E_2)$. The intersection $E_1 \cap E_2$ denotes the event that perception of the functional space occurs via both cameras at the same time. As E_1 and E_2 are independent events, we write $P(E_1 \cap E_2)=P(E_1)P(E2)$. The region of space in the scene that corresponds to $E_1 \cap E_2$ is visualized in figures 3c and 3d by means of yellow dashed lines. Comparing figures 3c and 3d it is noted that in figure 3c $camera_1$ is positioned at a location at greater distance from the functional space compared to figure 3d. This has several implications with respect to perception. One implication is that $P(E_1)$ takes a lower value in figure 3c compared to 3d. It is noted that $camera_2$ remains unchanged in both situations, so that $P(E_2)$ takes the same value in both cases. A second implication is that the union of the perception events occupies a smaller portion of the universe of discourse in figure 3c compared to 3d, so that $P(E_1 \cup E_2)$ is expected to be lower in the former case compared to the latter.

It is emphasized that the computations described up till now model the perception of an observer, who is viewing the functional space standing at both 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. This assessment should be expressed in possibilistic terms, namely as *possibility of perception*. This means the probability quantifying the perception of the scene by the observer should be converted to a possibility of perception. This is shown in figure 4. Figures 4a and 4b show the perception of the functional space by the respective cameras $camera_1$ and $camera_2$, i.e. the probability density functions $f_\theta(\theta)$ are integrated along angle dimension θ, yielding the perceptions $P(E_1)$ and $P(E_2)$. It is noted that both integrals have their center points at $\theta=0$ as seen in the figures. This is because for the surveillance purpose 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 $P(E_1 \cup E_2)$ is shown by the hatched area in figure 4c. Being an integral of the uniform pdf $f_\theta(\theta)=1/\theta_S$, $P(E_1 \cup E_2)$ corresponds to an angle domain θ', as seen in the figure. It is noted that $P(E_1 \cup E_2)$ 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

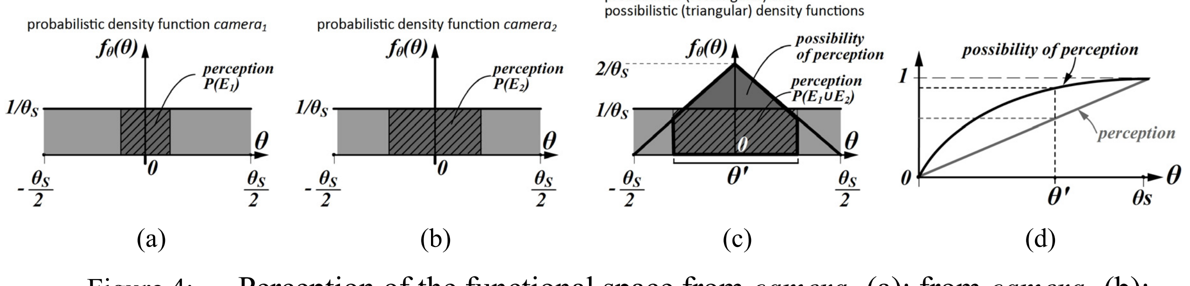


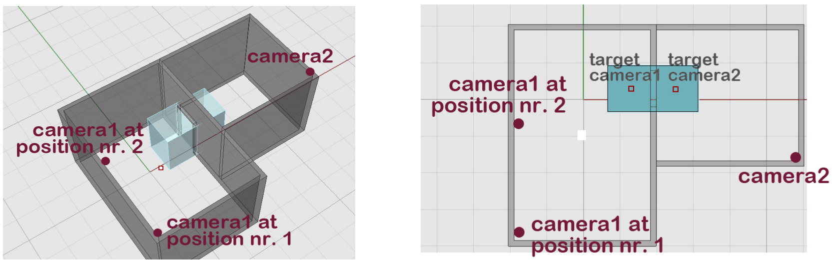
Figure 4: Perception of the functional space from $camera_1$ (a); from $camera_2$ (b); conversion of the union of the perceptions to possibility of perception (c); possibility of perception versus perception (d)

the uniform probabilistic density with respect to θ, namely $\theta=0$. Therefore, next to being the reference point for the perception computation simulating the immersion, the point $\theta=0$ also represents a reference point for perception possibility computation on the monitor. This is because 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 $\theta=0$. This yields the dark gray shaded area in figure 4c, 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 4d shows the relationship between possibility of perception versus the corresponding union of perceptions. From the figure it is seen that for a certain perception, there is always a perception possibility having a greater value than the perception. 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*, as described in Ciftcioglu, Bittermann et al. (2006).

It is to note that the possibility density function defined as a triangular fuzzy set in figure 4c is the counterpart of the probability density function with respect to perception along the *y*-axis shown in figure 2b lower, where 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.

3. Computer Experiments

Based on the methodology presented in the preceding section, two perception experiments are carried out, where $camera_1$ is placed at two different positions, while $camera_2$ is kept at the same position in the experiments. This is seen in figure 5a in a perspective view and in figure 5b in a plan view, where the functional space subject to surveillance is represented by the blue shaded box. 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. These points are denoted as camera targets in figure 5b. In order to compute the perceptions in the three dimensional scene, the solid perception angles Ω_1 and Ω_2 subtended by the object are obtained, as well as the solid angles Ω_{C1} and Ω_{C2}. The latter angles define the cameras' fields of view and correspond to vision angle in the perception computations described in section 2.1. This is accomplished by means of a probabilistic ray tracing. That is, vision rays are sent in random directions within the three dimensional visual scope, while the randomness in terms of Ω is characterized by $f_\Omega(\Omega)=1/\Omega_C$. This is conforming to the uniform pdf $f_\theta(\theta)=1/\theta_S$ that models the unbiased observer in the case of a two-dimensional perception plane seen in figure 2b upper. The uniform probability density with respect to the vision angle is accomplished by generating the three dimensional direction vectors of a ray using three random numbers, one for each

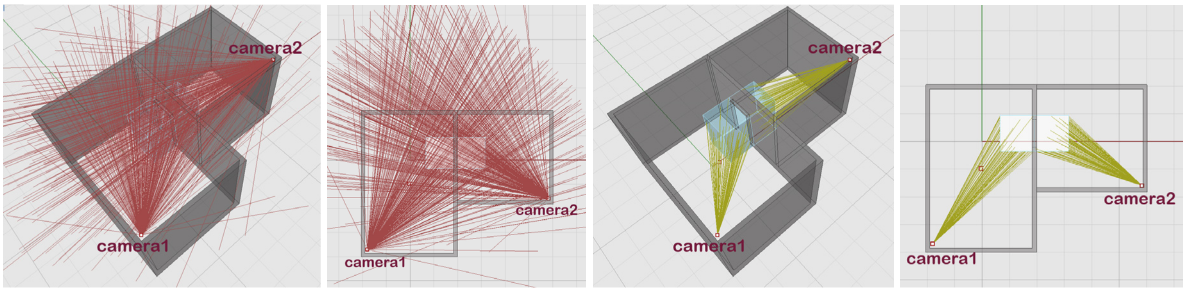


(a) (b)

Figure 5: Camera positions of the experiments in perspective view (a); plan view (b)

dimension. The random numbers are generated using respective Gaussian probability densities (Ciftcioglu, Bittermann et al. 2006); the following sigma and mean values are used for the Gaussians in the experiments: $\sigma_x=1.0;\ m_x=0;\ \sigma_y=.6;\ m_y=0;\ \sigma_z=1.0;\ m_z=3.0$, where the z-dimension is the direction from the camera towards the functional space, the y-direction points upwards, and the x-direction to the left seen from the observer. This corresponds to a visual scope with an angle of ca. 60º in the horizontal scope of vision plane. In both experiments the number of vision rays per observation position is $n_v=3000$. An object within the visual scope will be hit by a number of vision rays n_p, and these rays are termed perception rays. The perception of the object from an observation point is given by $P=n_p/n_v$.

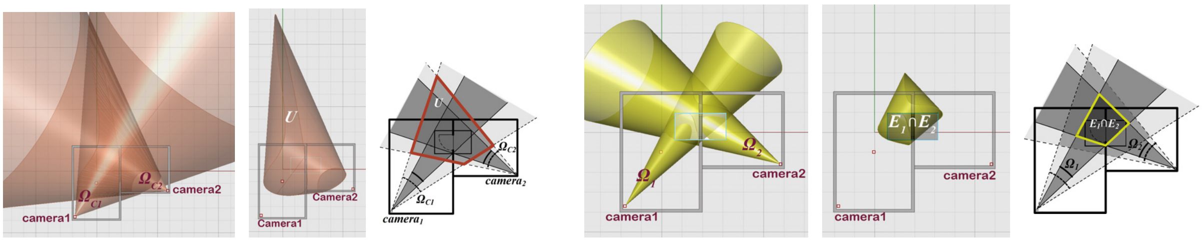
3.1 Experiment Number One



(a) (b) (c) (d)

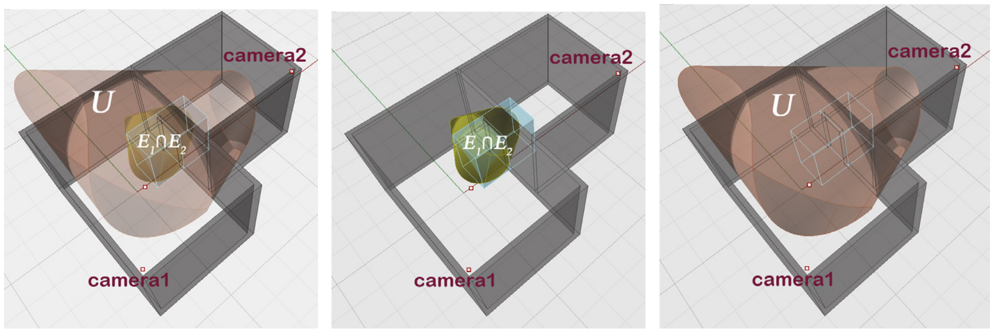
Figure 6: Rays modeling human vision in a perspective view (a); in plan view (b); rays among the vision rays hitting the functional space in a perspective view (c); in plan view (d)

In the first experiment the possibility of perception of the functional space is computed where *camera*$_1$ is placed at *position nr.1* seen in figure 5. Visualizations of the experiment are shown in figures 6, 7, and 8. The universe of discourse is formed by intersections of vision rays modeling the unbiased human vision, as seen in figure 6a and 6b. Those rays among the vision rays in figure 6a and 6b that hit the functional space are shown in figures 6c and 6d. The vision rays sent from the camera positions in figure 6a and 6b correspond to vision cones defined by the solid angles Ω_{C1} and Ω_{C2} shown in figure 7a. The Boolean intersection among the vision cones is the universe of discourse in this experiment, and it is shown as a rendering from a plan view in figure 7b and schematically as a projection into the horizontal plane in figure 7c. The rays hitting the object, seen in figure 6c and 6d correspond to the solid cones shown in figure 7d with angles Ω_1 and Ω_2, and they are termed perception cones. The intersection among the perception cones is shown as a rendering from top view in figure 7e and as a sketch in figure 7f. The universe of discourse and the intersection of perception events are shown for comparison in a single perspective view figure 8a, as well as separately in figure 8b, and 8c.



(a) (b) (c) (d) (e) (f)

Figure 7: Cones representing the human vision at the camera positions (a); universe of discourse (b); sketched projection of the universe of discourse (c); the cones representing the perceptions of the functional space (d); space corresponding to the union of the perception events (e); sketched projection of the perception intersection (f)

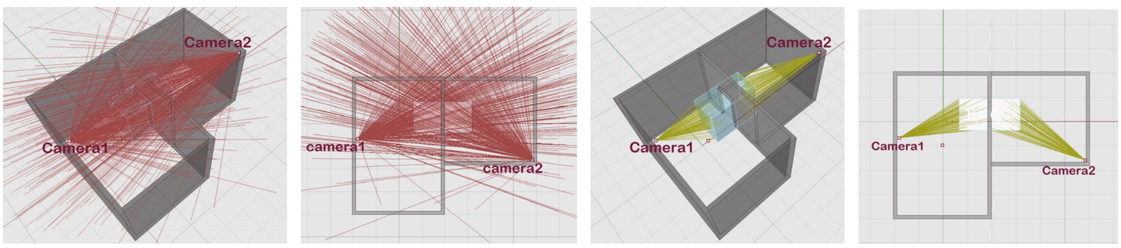


(a) (b) (c)

Figure 8: Universe of discourse and the intersection of perception events in a single perspective view (a); intersection of perception cones (b); intersection of vision cones (c)

3.2 Experiment Number Two

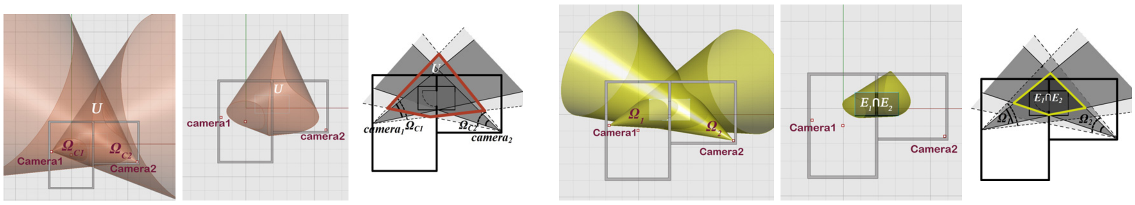
In the second experiment the possibility of perception of the functional space is computed where *camera₁* is placed at *position nr.2* seen in figure 5.



(a) (b) (c) (d)

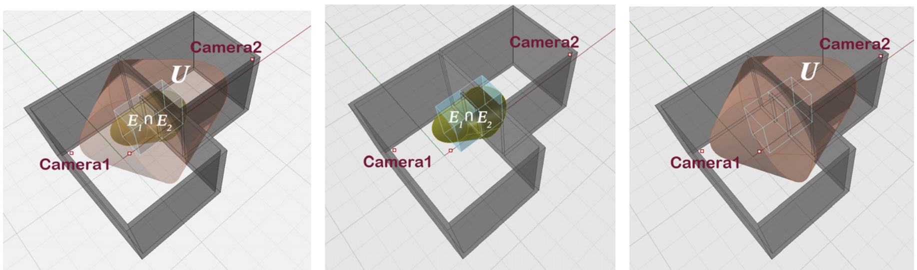
Figure 9: Rays modeling human vision in a perspective view (a); in plan view (b); rays among the vision rays hitting the functional space in a perspective view (c); in plan view (d)

Visualizations of the experiment are shown in figures 9, 10, and 11. The vision rays are seen in figure 9a and 9b. The perception rays are shown in figure 9c and 9d. The vision cones are shown in figure 10a. The universe of discourse is shown from a top view in figure 10b and schematically as a projection into the horizontal plane in figure 10c. The perception cones are shown in figure 10d. The intersection among the perception cones is shown as a rendering from top view in figure 10e and as a two-dimensional sketch in figure 10f. The universe of discourse and the intersection of perception events are shown for comparison in a single perspective view in figure 11a, as well as separately in figure 11b, and 11c.



(a) (b) (c) (d) (e) (f)

Figure 10: Cones representing the human vision at the camera positions (a); universe of discourse (b); sketched projection of the universe of discourse (c); the cones representing the perceptions of the functional space (d); space corresponding to the union of the perception events (e); sketched projection of the perception intersection (f)

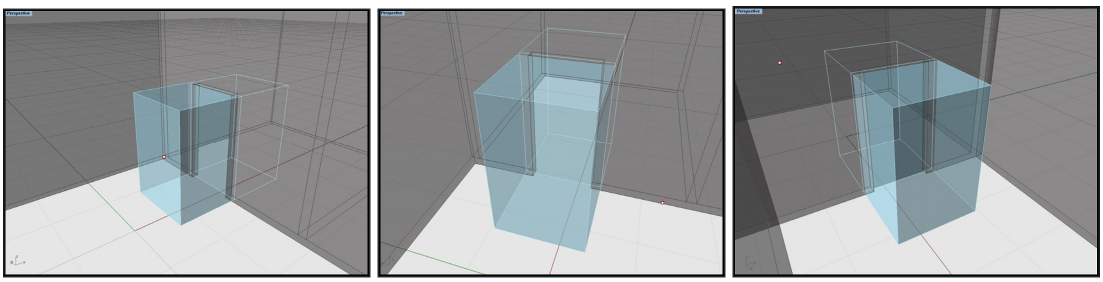


(a) (b) (c)

Figure 11: Universe of discourse and the intersection of perception events in a single perspective view (a); intersection of perception cones (b); intersection of vision cones (c)

3.3 Results

Figures 12a, 12b, and 12c respectively show the pictures of the scene taken from $camera_1$ at position nr.1, $camera_1$ at position nr.2 and $camera_2$. In experiment number one, perception $P(E_1)=.307$ (see figure 12a) and perception $P(E_2)=.445$, (see figure 12c), so that the union of the perceptions is $P_U=.615$ and the perception possibility becomes $p_p=.852$. In experiment number two, perception $P(E_1)=.478$ (see figure 12b) and perception $P(E_2)=.445$, so that the union of the perceptions is $P_U=.710$ and the perception possibility becomes $p_p=.916$. That is, in case the camera picture in figures 12a and 12c of experiment one are taken as the information source for the ambient surveillance, this yields a possibility of perception that is 8% lower compared to taking the images in figures 12b and 12c of experiment two. It is noted that the cause for the increased possibility in the second experiment is the increased union of probabilities in this case, which is due to increased perception via $camera_1$ from position nr.1 compared to position nr.2. It is emphasized that the perception is higher from position 2, as the functional space occupies a larger solid angle



(a) (b) (c)

Figure 12: Camera pictures from $camera_1$ at *position nr.1,* where $P(E_1)=.307$ (a); $camera_1$ at *position nr.2,* where $P(E_1)=.478$ (b); $camera_2$ where $P(E_2)=.445$ (c)

within the visual scope in this case. Considering the one dimensional projection of the case, the integral of the Cauchy function in (1) yields a larger value in the second experiment compared to the first one due to reduced value for the l_o parameter in the former case. It is interesting to note that the probability of the union of the perception events increases by 15%, while the possibility increases by 8%. This is explained considering that the possibility to see an object via camera image is already quite high for moderate perceptions, as seen from figure 4d, where possibility becomes saturated as the vision angle occupied by the object increases.

4. Conclusions

Human surveillance of a scene via two cameras is modeled by means of a probabilistic-possibilistic approach. The human observation via camera is modeled by means of perception, which is probabilistic in nature, and ensuing conversion of the perception into possibility, yielding possibilistic assessment of the perception. The latter step accounts for the fact that the observation does not concern a physical object, but visual stimulus that is mediated via monitor depicted camera image. Consequently the assessment of camera-induced perception is a fuzzy entity, which always yields a higher membership degree compared to the corresponding perception. It is noted that for possibility an underlying probability is necessary, and both quantities are respectively computed via integration of the associated density functions over some physical domain, for that matter the vision angle. The two computer experiments confirm the validity of the methodology. Possibilistic-probablistic perception simulation is suitable for precision assessment of surveillance of ambient environments. That is, the surveillance is uniquely assessed as a matter of degree, complementing a reported work in the literature, namely Bhatt, Dylla et al. (2009), where the assessment is carried out resulting in a binary statement in contrast with continuous assessment in this research. Using the novel approach, equivalent surveillance situations can be distinguished as not quite equivalent, providing one with enhanced decision making option. This may have an important impact in industrial applications, where a certain surveillance level is to be ensured for safety or security reasons, or where privacy concerns stipulate a maximum possibility of perception.

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