Lighting of RoboCup Games

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Abstract

This paper describes the philosophy behind our lighting of the RoboCup´99 games in Stockholm 1999. It also gives relevant background in the theory of light, lighting and colour in order to motivate our design. It is our hope that it will be a valuable source of information for future RoboCup game organisers.

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1. Introduction

This paper describes the philosophy behind our lighting of the RoboCup´99 games in Stockholm 1999. It also gives relevant background in the theory of light, lighting and colour in order to motivate our design. It is our hope that it will be a good source of information and reference for future RoboCup game organisers.

Robots playing soccer have the same need as a normal soccer-playing human – to be able to see the ball. But robots have higher demands on the lighting than humans, as we have yet to design a camera and visual system that is as good as the human eye. The demand that the robot must see the ball is thus the same as that it must see the ball with a normal CCD-camera.

What a CCD-camera needs in terms of lighting is very different from what a human needs. The lighting requirements become the same as the ones in a television studio: An even bright light that gives no large contrasts in the picture. The colour rendering must be as correct as possible as everything on the playing field is colour-coded. But the most important thing to have in mind, and which is easy to overlook, is that the lighting must be judged from the perspective of the robot. That is, the lighting shall be adequate from a viewpoint 20 to 40 centimetres above the ground (or from a point directly above the field in the case of the small league). This gives the all-important requirement in the middle sized and the legged league of even illumination of the vertical surfaces on the playing field.

When lighting levels are defined they are often specified as both vertical and horizontal illumination levels. Illumination is the amount of light that hits a flat object per unit area. It is measured in *lux*. When illumination levels are measured, it should be done with a lux-meter. It measures the light hitting a test area by integrating the light that hits it from a half sphere. When measuring horizontal illumination of the playing field the sensor of the lux-meter should be placed flat on the surface. When measuring vertical illumination the sensor should be placed vertical. This is most easily done by holding it against a flat panel that is placed facing the direction being measured.

Horizontal illumination is most important for small league teams using overhead cameras. For small league teams using robot-mounted cameras the vertical illumination level is the most important. This is also true for the legged and the middle-sized league. The horizontal illumination on these leagues is mostly important for the audience and the press as well as in documentation photography and video.

The vertical illumination is what lights the sides of the ball. It is only when there is an even illumination of the sides of the ball that it will be easy to analyse its colour. An even horizontal illumination may in the extreme case only shine on the top of the ball, making the sides progressively darker and the whole half-sphere below the midline completely dark.

The philosophy behind the lighting design presented below can be stated in a short sentence: *Reproducible, structured light for robotic vision*.

The lighting can be easily reproduced in most rooms, from small offices to large arenas. This makes it easier to adjust the robot at home and then find similar lighting conditions at the competition site. The use of spotlights facilitates this. Spotlights also give shadows from the players and the ball. This results in a structured light, which makes the situation more like real life. This gives an advantage to more robust solutions in vision algorithms, which are by us judged to be more interesting in a long-term perspective. Lastly the lighting in all the leagues, including the small league, is designed to make it possible to use robot-mounted cameras.

2. Lighting of Robotic Soccer

2.1 Lighting Fundamentals

Artificial lighting of sport activities is a fairly recent activity, which we today are totally dependent of. The practice of how to light a sport arena is still changing as new technologies, both in lamps and in the optics, are developed. But still there are some fundamental rules that will always apply when we use an artificial lighting fixture to illuminate an object.

A beam of light has a number of characteristics, but the most important one is that it does not stop. It begins in the filament (or spark) of the lighting fixture, and will continue to go straight out and be reflected until it has lost all of its energy (or is reflected so diffuse that we can not any more describe it as one ray of light). This is a big simplification of what light really is (wave-particle dualism etc.) and how it behaves (i.e. all sorts of modern physics), but quite enough for the discussion at hand.

For practical lighting purposes there are two kinds of lighting equipment that do not exist, but would be very helpful if they could be designed (indeed, several of the teams in Stockholm made requests that would require such lights). The first one is a light that stops, that is, a lamp that shines on the front of the goalkeeper, but gives no shadows of him on the back-wall of the goal. Or that shines on the top of the ball, but stops there and does not light up the playing field. The other one is light that does not come from a particular point in space. With such a light beam we could illuminate the bottom of a well without shining into the eyes of somebody standing at the bottom and looking up. Or illuminate the inside of the goal without having to block part of the goal with the spotlight.

All light that do exist must come from a point in space, most often a lighting fixture, and they will all give rise to shadows. A shadow can never be made to disappear by adding more light, as the added light will illuminate both the dark and light parts of the surface with the shadow. (If we add enough light, the non-linear sensitivity of the eye will reduce the effect of the shadow, but it will still be there, and is very easily picked up by a CCD-camera.) Softlights are one way of reducing the problem. They use a large illuminated area to illuminate the object, thus giving a diffuse light. They are available as special lighting fixtures, but diffuse light is also what we often experience indoors. The light from lighting fixtures does not only shine on our worktable, but also bounces on the walls and ceiling, thus adding up to a soft, diffuse light. Note, however, that we still have shadows: even on a cloudy overcast day outside, which gives a very diffuse light, the ground underneath a car will not be illuminated. And if we place a ball on the ground, the illumination on the ground decreases beneath the ball.

Figure 1. Softboxes from Photoflex

One way to provide RoboCup with soft light would be to place the whole field inside a white "tent" which is then illuminated from the outside (this is the same thing as using a number of larger softbox equipped lights as in figure 1). This is not a practical solution, as it does not allow for spectators to view the game and the equipment and arenas needed will be bigger and more expensive than necessary.

When we use a lighting fixture of some kind, the light from it can be said to have a number of different qualities: The main ones are:

Intensity	How bright the light from the fixture is.
Colour	What we will see if we illuminate a white paper with the fixture.
Sharpness	How details in an illuminated object will be portrayed, also influences the shadows.
Shape	Where the light shines, and where it does not.
Focus	The general direction of where the light shines

Choosing the fixture sets these parameters; some can be altered in various degrees afterwards by various means.

The basis for the lighting design was taken from "Guide to the artificial lighting of football pitches", which are written by FIFA and Philips Lighting B.V. in cooperation and gives guidelines for the lighting of human soccer games. As one of the long-term goals for RoboCup is to produce bipedal robots capable of playing (and winning) against humans, these are the lighting conditions that RoboCup should try to converge to. The guidelines describe four different categories of people that need lighting of the game: the players, the technical staff, the spectators and the media (TV and photographers). All of these have different needs, and the lighting installation should provide adequate lighting for all these different groups. In RoboCup mostly the needs of the players have been looked after. At the RoboCup games in Stockholm, we tried also to fulfil the needs of the other three categories.

The guidelines describes a number of areas in which the specifications must be fulfilled:

- Illuminance of the horizontal plane
- Illuminance of the vertical plane
- Uniformity
- Glare restrictions
- Modelling and shadows
- Colour and colour properties
- Design

We will describe these items in detail in this document, and give our recommendations for RoboCup games. The guidelines also specify how the measurements are to be made.

2.2 Equipment

Fresnel Spotlight

The lighting fixture of our choice for lighting the RoboCup games is the Fresnel spotlight (figure 2). It consists of a lamp housing with a concave mirror behind the lamp and a fresnel lens at the front. The fresnel lens can be seen as a very thick lens which have had most of the glass inside taken out, leaving only the front and back surface. The lens will function similar to the original lens, but with a much reduced weight. In addition, the fresnel lens makes a large shining surface, due to imperfect reflections in the many surfaces, and the sharpness of the lamp is therefore reduced. The shadows will be softer, and less contrast will appear on objects illuminated. The housing incorporates a mechanism for moving the lamp, thus making it possible to alter the shape of the light: the angle of the cone of light from the fixture can be varied. The possible range of angles is from about 6 degrees to 70 degrees. The fixture can also be outfitted with filters, either for colour correction or diffusion filters, which makes the light even softer. The standard equipment also includes “barndoors”, which are four rigid steel panels that can be used to mask the light coming out of the spotlight. We can thus influence the shape of the light further. Other advantages of the fresnel fixture is that it is light, compact and readily available in large quantities from rental houses as it is a standard item for stage and film productions.

Figure 2. 1 kW fresnel spotlight by Arri.

Dimmers

A dimmer is a very useful component in a lighting installation, especially if the illumination has to be adjustable in intensity. It is our recommendation that all lights at RoboCup games should be connected to a dimmer, including the small league. This makes it possible to adjust the lighting to be within the specified illuminance. It also makes it possible to adjust the lighting with respect to existing lighting in the room. Care must be taken that when the levels of incandescent lights are adjusted by the dimmer their colour temperatures change. This makes it necessary to have a reliable method of resetting the levels to exactly the same level when the lights are brought up again. A programmable lighting desk facilitates this operation a lot. Another plus of having an easy way of adjusting the light levels is that the lights can be brought down between games. This will reduce the heat from the lamps, and thus decrease the temperature in the room where the game is taking place. In Stockholm each middle-sized field were illuminated by lamps consuming total of 20kW of power, almost all of which becomes heat. Some rooms became very hot after a day full of games.

2.3 FIFA Regulations and RoboCup

The main parameters in the FIFA guidelines are the illuminance of the field, the glare restrictions and the colour temperature. We will here describe how they affect the lighting design for RoboCup games.

Illuminance Levels (lux) for Horizontal and Vertical Surfaces.

The RoboCup regulations call for an even lighting. It does not say anything about in what respect the lighting should be even. We propose that it should be read as to be even both when viewing the field from above and when viewing objects on the field from a robots perspective. That is, both horizontal surfaces, such as the field, and vertical surfaces, such as the sides of other robots and the ball, should be illuminated evenly. In the small league the horizontal illumination is most important, as most teams are using a camera placed above the table. But in order to make it possible to use the more complex set-up with robot-mounted cameras, an even vertical illumination should be ensured. This is also important for the spectators and media coverage of the matches. In the middle and legged league the cameras are mounted on the robots, and the vertical illumination is the most important. The horizontal illumination is of secondary importance, but if the vertical illumination is even across the field and in all directions, the horizontal will also become even. Important is also that if we place the lights in a way that avoids glare, the amount of illumination as measured in lux can not be the same in the vertical and horizontal direction. The horizontal illumination will always be greater. For the case when the lights are placed at 30 degrees from the horizontal, the vertical illumination will be 40% of the horizontal.

The horizontal illumination is measured with a probe placed horizontal, flat, on the playing filed. The illumination of vertical surfaces is measured with the probe at 90 degrees to the playing field. The vertical illumination must be measured in four directions. The FIFA regulation mandates the measurements to be made in the directions that are parallel with the sides of the field. The illumination should be measured at a number of different points on the field. Appendix A gives recommendations about placement of measurement points for the different leagues.

Glare 30-60 Degrees

It is important to avoid glare, which is what we experience when looking into a sharp light. Glare occurs when the ratio between the brightest spot and the average level of a scene viewed is too large. When it is, the human eye (or the robot camera) will adjust its gain to the brightest part of the scene, and then have trouble making out the darker parts. The main source of glare in the case of RoboCup is when the cameras on the robots are able to look directly into the spotlights. In order to minimise this there are no lights placed lower than 30 degrees from the horizontal, measured from the position on the field they are directed at. This makes it possible to use a robot-mounted camera with a field of view (FOW) of 60 degrees looking straight forward, or a camera with a FOW of 90 degrees looking slightly down (figure 3). The recommendation for lighting of sports fields for humans is to not have any lights below 25 degrees from the horizontal.

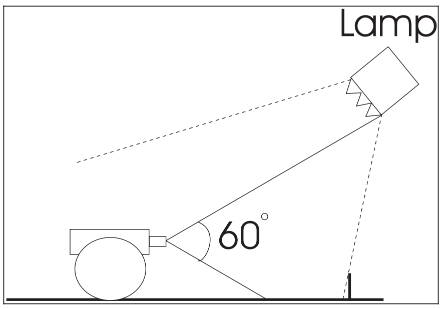

Figure 3. Keep the lights out of the FOW.

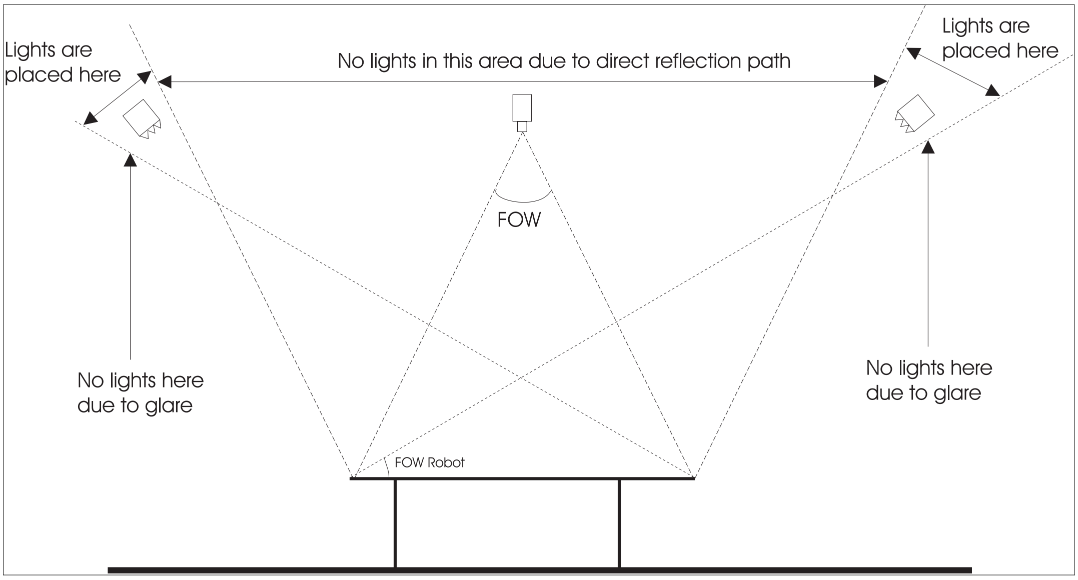

Figure 4. Possible areas for placement of lights in the small sized league.

Another source of glare is diffuse reflections. These are usually no problem in the middle and legged leagues, but must be taken into account in the small league. The placement of the cameras above the playing field makes it possible to have a direct reflection path from one spotlight to the camera by the field (figure 4). This is possible as the field will work as a mirror and reflect the light. This gives an area of the field that has a much higher luminosity than the rest of the field. The spotlights must be placed as far apart from the field as is necessary in order to remove this possibility. In the RoboCup'99 the spotlights were placed as to remove the reflection path to a camera mounted at the centre of the field. The case of two cameras being used is also covered by this placement, as long as each camera is only being used for half of the field. This positioning of the spotlights also gives rise to shadows from the robots, the ball and the sides of the field. These are very hard to reduce, as long as we want a relatively simple and compact way of lighting the games (see discussion of softlights above). As the existence of shadows is a natural phenomenon, existing in all real-world soccer games, they are not against the intentions of RoboCup. The adaptation of vision algorithms to be able to handle these kinds of shadows will make the algorithms more robust and facilitate use of them in other applications.

Colour

Colour is one of the hardest concepts in lighting to understand, mostly because we take it for granted. It is easiest to describe by what it is not: Colour is *not* the wavelength of the light reflected by an object. The colour perception of the eye is not a frequency discriminator that takes the dominant wavelength and ascribes the colour of the object after it. In fact, for each colour we can perceive, there are an infinite number of combinations of wavelengths that will give rise to it. The human concept of colours, including phenomena such as primary colours and opponent pairs, do only exist inside the human mind.

The players of RoboCup do most of the time use a CCD camera as an eye. The CCD camera differs in some ways from the human eye, most notable in the frequency response of the three colour receptors used (red, green and blue). A CCD camera cannot record all the different colours that a human can perceive. Some high-order processes in the human brain are also not present in the camera, which makes it necessary to tell the camera what is to be recorded as pure white. This is done by a manual or automatic process of setting the white-balance. A human makes an evaluation of the colours of the lighting and the objects in a room, matches this with prior knowledge of what colours some objects should be, and thus can calculate the colour of unknown objects, even under lighting conditions that differ a lot from sunlight. The CCD camera does not have this knowledge, which is why we have to calibrate the white-balance. The calibration is only valid under the lighting conditions where it is made, and with the illumination having a constant colour temperature. This makes it important to use lights that have the same colour temperature over time when illuminating a RoboCup field.

Colour Temperature

A black body that is heated will give rise to an emitted spectrum of electromagnetic radiation. When heated enough, the radiation will have energies that makes it visible as light. This is essentially what is happening when a piece of iron is heated in the forge: it goes from black to red to white to blue as the temperature increases. The colour, and thus the spectrum emitted will be uniquely dependent of the temperature of the black body radiator. The maximum of the output spectrum will change, and thus not only in how it looks to the eye, but also in how it will reproduce other colours when reflected. Thus we call the temperature of a blackbody that gives rise to a certain spectrum for its blackbody temperature. Only things that gives out visible light due to being heated does have a true colour temperature. The most common one is incandescent lamps, with tungsten as the glowing part. Other types of luminaries often have a colour temperature attached to them, for example fluorescents, but this is only an approximation. A blackbody-radiator have a continuous output spectra, but a fluorescent does only have a discontinuous spectrum of lines. The colour temperature ascribed to it is the one an incandescent lamp would have that would give the same colour sensations to the human eye, as judged by human test subjects. Great care must thus be taken when using fluorescents and arch-lights, such as HMI and CDI etc. with CCD-cameras. Colour temperature measurement equipment often gives a false reading when used with a non-incandescent source.

The recommended colour temperature for televised events is 4000 K. But lamps with this high colour temperature and with a good colour rendering index is most often found as Metal-Halide lamps, which are more expensive and more difficult to handle compared to ordinary incandescent lights. The recommendation in appendix A of 3000 K is achievable by ordinary film and theatrical spotlights.

Colour Rendering Index

In order to have a measurement of how good a line spectral source, such as a fluorescent lamp, is to reproduce colours, a Colour Rendering Index, CRI, have been standardised. All incandescent lamps have a CRI of 100 by definition. This as they have a continuos spectrum, and will reproduce all colours perceptible with the human eye faithfully. A fluorescent light is given a CRI by judging its colour rendition against a number of standard colour samples. It is important to remember that this is done by comparing them using the human eye. Two lights that have the same CRI may still have widely different colour renditions if used together with CCD cameras as the CCD-camera's three sensors do not have frequency responses that are identical to the cones in the human eye. Some fluorescents are specially tailored to CCD-cameras, and are very useful for television and may be suited for RoboCup games.

3. League Specifics

3.1 Small

The field was lighted with four spotlights of the fresnel type. They were placed at the extended diagonals of the field, and at the same height as the cameras. They were also placed at the same horizontal distance from the corner of the field as the centre of the field (see fig. 4). This was done to ensure that we did not get a direct reflection path on the table, and by that a problem with glare. The spotlights on each short side were mounted on a horizontal 5 meter long pipe, which in turn was mounted on two stands, which were extended to the correct height. If the spotlights are placed any closer than this, there will be a problem with glare. The downside of this arrangement is that the sides of the field does gave rise to shadows. The lamps had a colour temperature of 3200K. The total power consumption per field was 4kW, which gave a grand total of 16kW for the round robin games, and 8 kW for the finals when only two playing field were used.

Figure 5. Photo from RoboCup´99. Visible is the pipe at the end of the field with two fresnel lights. Also visible is the truss going along the midline of the field were the cameras are mounted. One of the cameras can be seen being mounted on a magic arm. This truss is possible to lower without moving the pipe with the lights. The playing field is placed on the floor.

Figure 6. Overview of the preliminary games in the small league. Noticeable is the black paper taped on the floor around the field in order to reduce glare. The placement of the lights did in this case only eliminate glare on the playing field itself.

The cameras were mounted a rigging truss which were 6 meters long and supported by a support at each short end of the field. The supports were placed as far as possible from the table, in order not to give any shadows on the field. The cameras were mounted on the truss with clamps that were supplied by us. The clamps we used were ”SuperClamps” by Manfrotto, and they worked very well (figure 7). We also had a number of ”Magic Arms” available. These makes it possible to easily place the camera with 6 degrees of freedom, instead of the 2 degrees which the clamps offer in themselves (figure 8).

Some teams requested a lighting design that would give a very soft light on the whole field. This is very hard to do in the localities were the games were held, especially with the added constraint of the cameras being mounted 3 meters directly above the field. The design we used has the benefit of being very easy to set up, it does give an even light on the whole field, and it should be possible to reproduce in most labs. The problem with the shadows from the sidewalls are today very much reduced, as their shape have been changed.

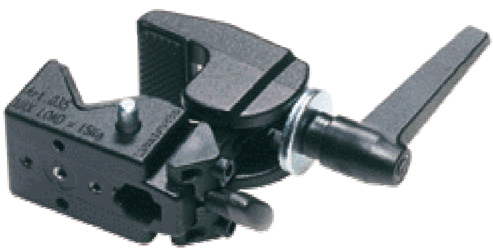

Figure 7. Superclamp by Manfrotto

Figure 8. Magic Arm by Manfrotto

3.2 Middle

The size of the rigging at RoboCup'99 was 10m by 6.5m. The total height of the rigging was 3m, except for the finals were it was extended to 3.5m. The lighting consisted of 20 pieces of 1kW fresnel spotlights, all with a colour temperature of 3200 K. All the spotlights did also have diffusion filters installed, in order to even out the illuminance and to make the shadows less sharp. The exact layout of the light is shown in figure 9. The installation also included a dimmer and a lighting desk. This set-up was only used as a power splitter, all the lamps were on at 100% during all the matches. This gives a total power consumption of 20kW, which were supplied by a 340V/32A cable.

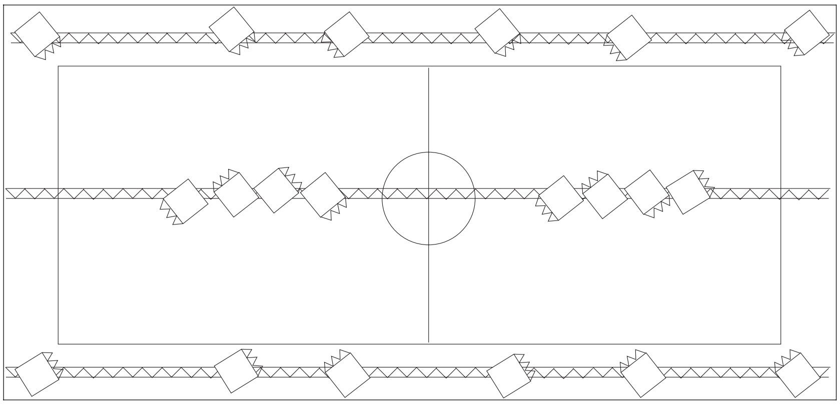

Figure 9. Schematics of the lighting for the middle sized league at RoboCup´99.

Figure 10. Photo from RoboCup´99 showing part of the lighting installation for the middle-sized league.

Figure 11. The venue for the legged league at RoboCup´99.

3.3 Sony Legged

The field was lighted by four spotlights, in the same fashion as in the small league. The spotlights were hung from a truss that was at a height of 4 meters. This was used in order to accommodate the video projector and the viewing screen which were also a part of the design. The Sony robots ”Aibo” are made for indoor lighting conditions, and thus for low light levels. The average horizontal lighting was at 1000 lux, with a vertical level of 600 lux. This was achieved by having the dimmer running the lights at about 70% (quadratic dimmer curve).

4. Tricks of the Trade

4.1 Filtering

Filters are the magic tools of lighting. They can change a warm incandescent into a cool fluorescent. Or they can make the sunlight through the window look like an incandescent. They can also reduce the intensity of a spotlight, or soften up a light by diffusing it.

One big hazard with filters is that they age, and change colour and other properties, when they become hot. This ageing is gradual with time and temperature. As the RoboCup tournaments are long, and the lamps are on more or less the whole time, this ageing can become very noticeable. This must be taken into account, and filters, is used, must be exchanged before they have changed significantly. This is important to ensure the same conditions for all the participants and all the matches.

The most useful filter for RoboCup is the diffusion filter. This looks like a piece of white plastic or fabric, and is placed in front of the lens of the spotlight. It will diffuse the light, making shadows more fuzzy and even out the illuminance across the playing field.

Colour correction filters may also be useful. Especially the Sony Aibo robots seems to be designed to work under fluorescent light, which is much bluer than incandescent. This can be adjusted with a colour correction filter. But as these robots most often use very precise calibration, the filters must be exchanged regularly in order to guarantee the same conditions throughout the tournament.

"Neutral density" filters may be used to reduce the brightness of the field. Our recommendation is not to use these on the spotlights, as they work by converting light to heat, and thus will age very fast. Instead use them on the cameras of the teams that have a problem with the illuminance levels. Care must be taken to mount them flat on the lens. As they will become a part of the optic system, the same care should be taken with regard to dust, scratches, flatness etc. as when working with any other optic component.

4.2 Caps on Cameras

If a robot has a problem with glare due to the lights being placed low (for example due to a low ceiling), it can easily be fixed by giving the robot a baseball cap. Just cut out a half-circle from black paper, and tape it above the camera in order to shut out the direct light from the spotlights.

4.3 Camera Mounts

The small league uses cameras mounted above the field. Our recommended set-up is a piece of truss spanning the field across its length. It is convenient to use stands that are easily raised and lowered by a crank. The truss should be long enough so that the stands can be placed in between the spotlights to not get any shadows from the stands on the field. In order to mount the cameras on the truss we used "Superclamps". These are easily mounted on the truss, and with the correct connector stud it is possible to mount most consumer cameras on them. For the teams that required more flexibility in the camera placement, we also had a number of magic arms available.

Figure 12

Truss by Manfrotto

Figure 13

Wind-up stand by Manfrotto

Figure 14

Camera Stud

5. Other Sources of Light

5.1 Sun

As the CCD-cameras are sensitive to the colour temperature of the lighting, care must be taken to keep it constant. If we mix in sunlight, direct or reflected from clouds etc, with the artificial lighting, the colour temperature will change. All external sunlight should therefore be blocked from the playing field.

5.2 Video Lights/Flashes

Flashlight photography have been blamed for a lot in the games. It should be restricted, but our experience gives that they at most destroy one frame in the video stream. A robust robot design should detect this.

Video lights are a bigger problem. Strict instructions should be given to visiting video crews that no extra lighting are allowed. As the playing fields are already lighted for robots the illumination should be adequate for all modern video cameras.

5.3 Shadows of People

People shadowing the field will influence the illuminance. Care must be taken by the referee and by external photographers so that they do not shadow the playing field and the ball during play.

References and Further Reading

C.L. Hardin, *Color for Philosophers*, Hackett Publishing Company, 1988.
(Good reference for understanding of what colour really is and what it is not).

Guide to the artificial lighting of football pitches, Approved by Federation Internationale de Football Association, Philips Lighting B.V., Lighting Design and Application Centre, PO. Box 80020, 5600 JM Eindhoven.

Lighting manual, 5th ed. ,Philips Lighting B.V. 1993. ISBN 90 801262 1 7.
(Good introduction to technical and sports lighting).

Photos in figures taken from the web-pages of

Manfrotto www.manfrotto.com

Photoflex www.photoflex.com

Photos from RoboCup´99 by Anders J Johansson.

Appendix A

Lighting specification for RoboCup

Definitions

E_h Average maintained horizontal illuminance at the level of the playing surface

E_v Average maintained minimum vertical illuminance at the height of half of the respective leagues maximum height, measured parallel to the four sidelines of the playing area.

U1 Uniformity E_{min}/E_{max}

U2 Uniformity $E_{min}/E_{average}$

T_k Colour temperature in Kelvin

R_a Colour rendering index

Glare

The preferred angle of lighting is at least 25 degrees vertical relative the centre line of the field. The angle should not exceed 60 degrees in order to be able to give good vertical illuminance.

Recommended minimum values

			Horizontal		Vertical			
	E_h	**E_v**	**U1**	**U2**	**U1**	**U2**	**Ra**	**T_k**
Small league	700	-	0.6	0.7	0.4	0.6	65	3000
Small league, mobile cameras	700	700	0.6	0.7	0.4	0.6	65	3000
Middle league	*	700	0.6	0.7	0.4	0.6	65	3000
Legged league	*	700	0.6	0.7	0.4	0.6	65	3000
Televised event	(1000)	1000	0.6	0.7	0.4	0.6	65	4000

Comments: (*) The vertical illuminance criteria will secure adequate horizontal illuminance.
Vertical illuminance should be measured at points indicated in figure A1, A2 and A3.

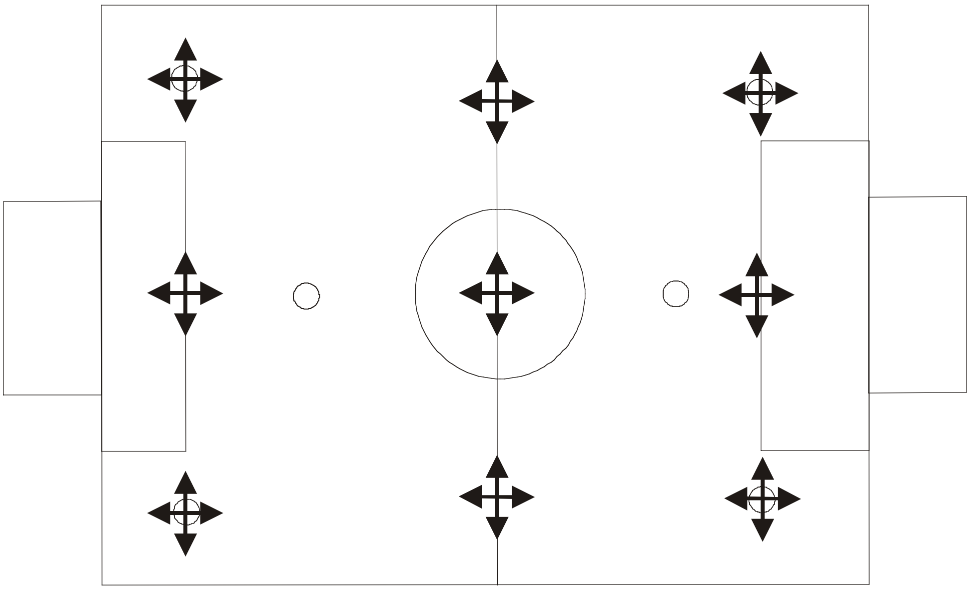

Figure A1. Small league. Illumination to be measured at vertical planes as indicated by the arrows. Measurements to be taken at 10 cm height.

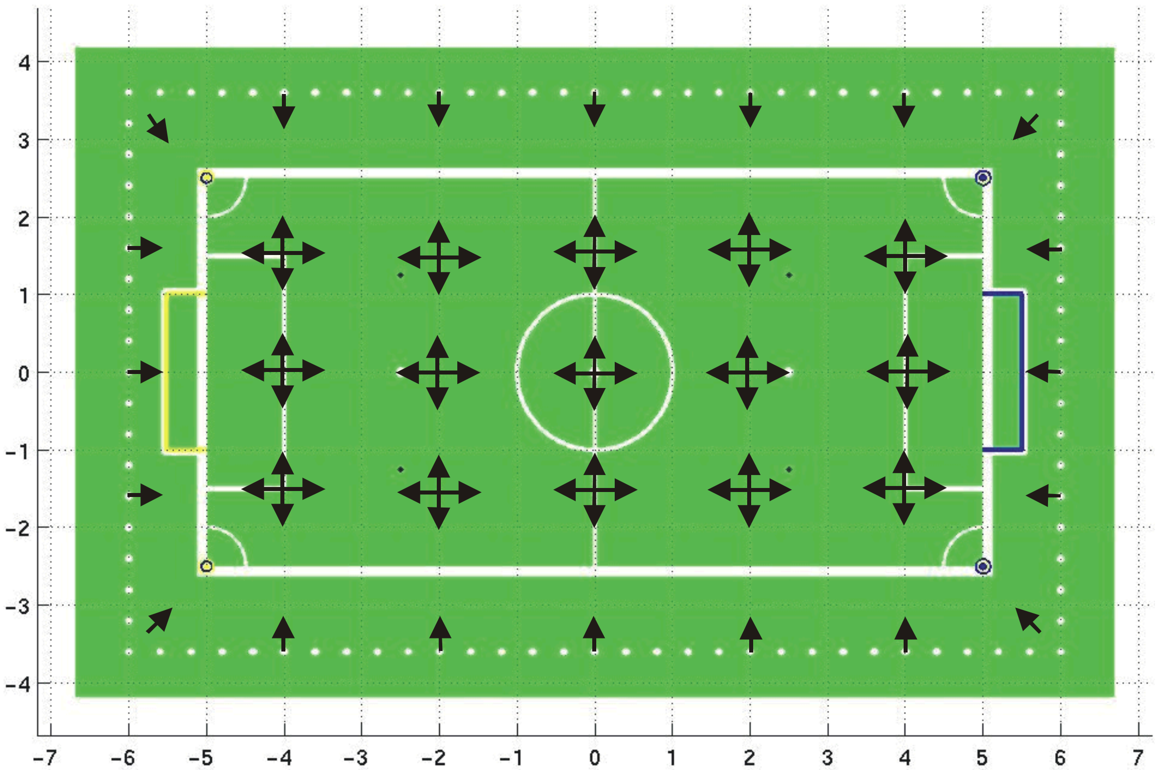

Figure A2. Middle league. Illumination to be measured at vertical planes as indicated by the arrows. Measurements to be taken at 50 cm height.

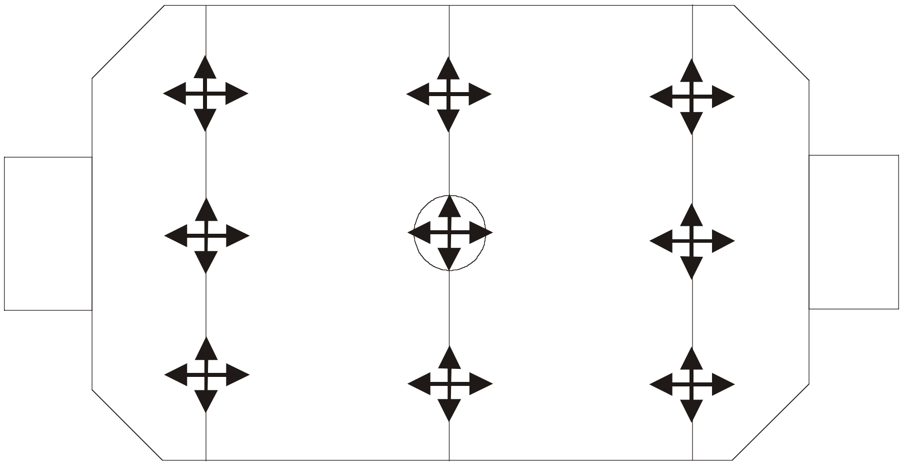

Figure A3. Legged league. Illumination to be measured at vertical planes as indicated by the arrows. Measurements to be taken at 20 cm height