Soccer Dribbler Design for the Eagle Knights RoboCup Small Size Robot

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***Abstract* - This paper describes the design of the Eagle Knights robot soccer dribbler in the context of RoboCup Small Size League. The paper presents the mechanical design considerations for the dribbler comparing to previous Eagle Knight dribbler designs as well as other teams. The design for the latest Eagle Knight dribbler generation is presented showing results for a number of experiments performed on the dribbler to test its effectiveness. A number of factors have been identified and used for experimentation. Results are discussed and conclusions are presented.**

***Keywords* – RoboCup, Dribbler, Robot Soccer, Mechanical Design**.

I. INTRODUCTION

The architecture of a RoboCup Small Size League (SSL) team consists of four main elements: Vision System, Artificial Intelligence (AI) system, Referee Box and five remotely controlled robots [1], as shown in Figure 1.

The vision system digitally processes two video signals from cameras mounted on top of the field. It computes position and orientation of the ball and robots on the field. This information is transmitted to the AI system responsible for making strategic game decisions.

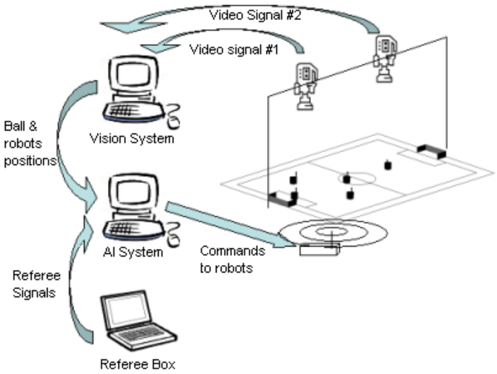

Fig. 1. Architecture of a RoboCup SSL team consisting of a Vision System, AI system, Referee Box and five remotely controlled robots.

The actions of the team are based in a set of robot roles, e.g., goalkeeper, defense, and forward, depending on a general game strategy and according to the current state of the game. To avoid collision with other robots, in particular those of the opposite team, potential fields are used as a critical element in the AI system [2]. Game decisions are converted to play commands that are sent to the robots via a wireless link. The robots execute these commands and produce mechanical actions as ordered by the AI system. This cycle is repeated 30 times per second. Additionally, the referee transmits game related decisions such as penalties, goals, start of game, end of game, etc. These commands are sent to the AI system through a serial link. Each robot in the team is responsible for effectively executing commands sent by the remote AI system via the wireless link. Robots include specialized electronics to communicate with the remote computer and control local robot actions.

The robot mechanical design is divided into four components as shown in Figure 2: *Movement*, *Control of the ball, Shoot/Pass* and *Protection* [3]:

- **Movement** relates to geometry of the motors, design of the wheels and number of rollers (smaller wheels) in each wheel.
- **Control of the ball** relates to dribbler design, including diameter, gears and motor.
- **Shoot/Pass** relates to kicker design for shooting or passing the ball.
- **Protection** relates to robot cover protecting the most fragile pieces of the robot.

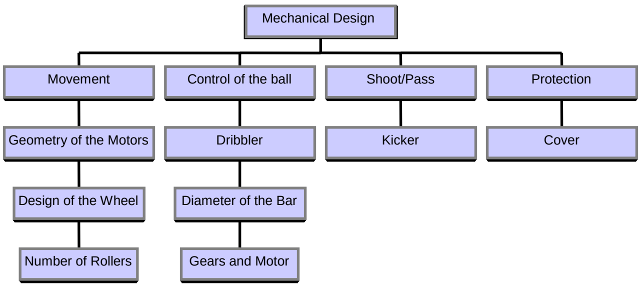

Fig. 2. Robot mechanical design components consisting of *Movement*, *Control of the ball*, *Shoot/Pass* and *Protection*.

Dividing the mechanical design in four general components simplifies robot design and facilitates identification of critical zones. An analysis of the areas with, for example, greater mechanical wearing can then be made to correct and improve global performance of the robot.

A block diagram is included in Figure 3 showing the robot mechanical design. Each arrow in the diagram indicates pieces that interact with each other to facilitate the understanding of robot component interdependencies.

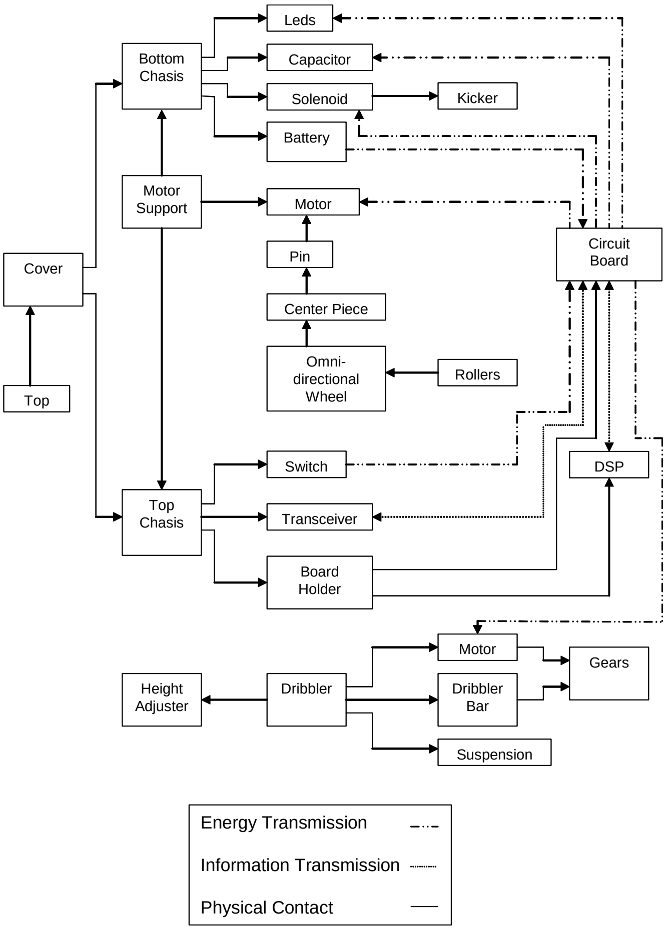

Fig. 3. Block diagram showing interdependencies between robot components. These dependencies can be of three types: energy transmission, information transmission and physical contact.

The objective of this work is to provide a framework for the design of the robot dribbler component specifying experiments to be made on the system. The organization of the paper consists of Section II describing the dribbler mechanics, Section III describing dribbler design considerations, Section IV describing experiments and results, and Section discussing conclusions.

II. DRIBBLER MECHANICS

This section describes the mechanics of the dribbler system designed by Eagle Knights, comparing it to previous designs from older generations while also contrasting it to designs from other teams.

A. MECHANICS

The dribbler is an integral small-size robot component that includes a bar, DC motor and two gears to transmit power from the motor to the bar as shown in Figure 4. When the ball is inside the LEDs zone a signal is sent to the robot controlling unit to start the dribbler in order to create a “suction field” keeping the ball tight into the robot. The LEDs are also important for kicking. In order to have an efficient dribbler, the bar must be made of an appropriate material that allows good control over the ball while the robot is moving and provides enough power to strip the ball from an adversary when two dribblers compete against each other for ball possession. The bar height and the point where the ball makes contact with the bar may lead to better or worse control of the ball.

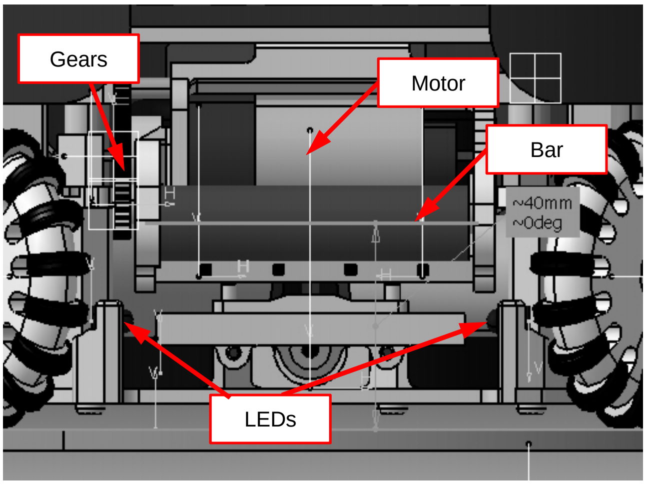

Fig. 4. The dribbler subsystem includes a DC motor and gears to transmit power to the bar. Two LEDs sense whether the ball is in place for dribbling (and kicking).

In Figure 5 we show an image of the robot holding the ball. In the image it is possible to observe the bar at an appropriate height where the ball can be grabbed from approximately a quarter of its depth. In the same figure it can be seen the zone where the bar is in contact with the ball and the ball with the bottom chassis.

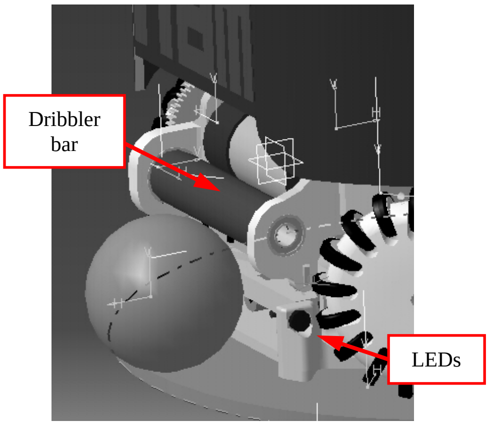

Fig. 5. The dribbler subsystem showing the dribbler bar and the location of the LEDs. The diagram also shows the ball in relation to the dribbler mechanism.

Regulations specify that the ball can be at most a quarter of its diameter inside the robot. Thus, if a larger portion of the ball is inside the robot, the robot will be breaking the ball possession rules. On the other hand, if the bar is below an optimal height, this would decrease the control over the ball and the bar contact point with the ball would not generate enough pressure with the ground. Moreover, the ball would not get into the LEDs zone disabling effective dribbling and kicking. These aspects affect both kicker and dribbler design considerations, such as bar width and height and consequently its effectiveness.

B. COMPARISON

Eagle Knights (EK) team has participated in RoboCup Small-Size League since 2003. Our first dribbler design consisted of a very crude system having a motor and a bar that did not properly work. In 2004 we did a complete dribbler redesign using a tube of *nylamid* plastic covered with rubber washers as shown in Figure 6. The bar had a large diameter and occupied a large space in the robot. A Maxon DC motor activated the dribbler using two gears with 38 teeth each. Power was transmitted using a 1 to 1 relationship between motor and bar.

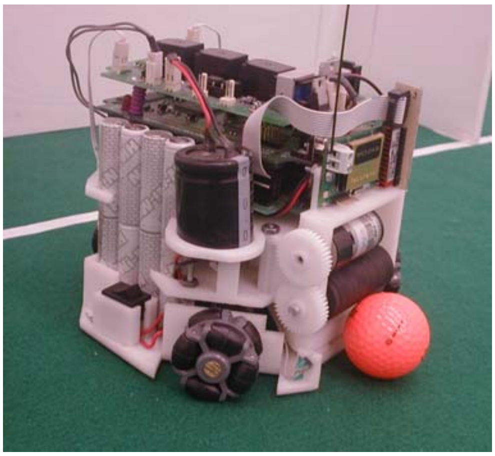

Fig. 6. EK Small Size Robot 2004. The picture shows the dribbler component in the front in contact with the ball. The dribbler includes a motor, a bar made of about a dozen "washers" and two white gears. One of the LEDs can be seen at the left of the ball.

The performance of the 2004 dribbler was erratic. We did not perform at the time an in depth analysis to understand the factors causing its malfunctioning. In 2005 we developed a new robot and mostly reused the previous year dribbler design as shown in Figure 7. Modifications included a smaller bar diameter and different bar material. The 2005 design includes a more powerful although heavier Faulhaber motor instead of the previously used Maxon motor. The increased robot frontal weight and the higher motor and bar position, close to 68 mm from the ground, caused some increased robot instability. The gears driving the new bar were of 56 and 19 teeth increasing the power relation to almost 3 times the revolutions of the motor.

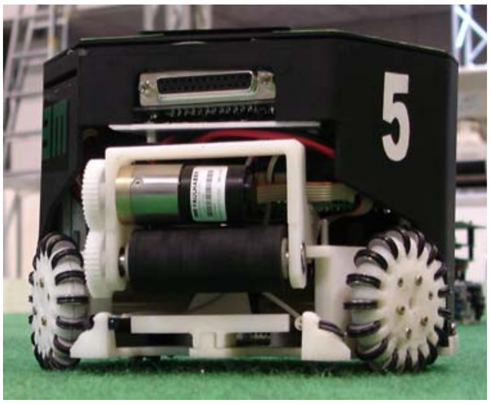

Fig. 7. EK SSL Robot 2005. Dribbler design was somewhat similar to 2004. The main change was the use of a more powerful although heavier motor from Faulhaber and a larger dribbler height due to larger omnidirectional wheels.

Due to poor results from both dribblers we carried out a more in depth analysis of other teams designs. The documentation of some equipment was reviewed, such as Cornell University Big Red [4] team shown in Figure 8. Their dribbler used vinyl to elaborate the bar and included a suspension mechanism to cushion ball impacts.

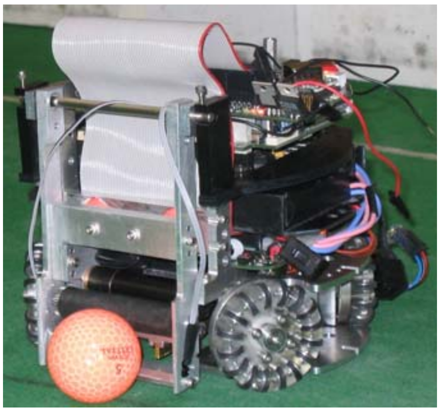

Fig. 8. Big Red SSL Robot 2005. The dribbler uses vinyl to elaborate the bar and includes a suspension mechanism to cushion ball impacts.

In Figure 9 we show a picture of the dribbler mechanism used by the Fu-Fighters team from the Free University of Berlin [5]. The dribbler includes a separation in the middle of the bar to center the ball.

Fig. 9. Fu-Fighters SSL Robot. The dribbler includes a separation in the middle of the bar to center the ball.

In Figure 10 we show the CMU-Dragons of Carnegie Mellon University [6] having a dribbler with suspension system similar to the one used by the Big Red team.

Fig. 10. CMDragons SSL Robot. The dribbler uses a suspension system similar to the one used by the Big Red team.

III. DRIBBLER DESIGN

In 2006 we decided to design a new generation of the EK SSL robot together with a new dribbler. The work presented on the rest of this paper is based on this latest dribbler design. The dribbler goals were set to include the following considerations:

- A more extensive angle of reception for the ball.
- A new dribbler bar material for better ball control.
- A decrease in bar diameter to reduce weight and volume.
- A smaller dribbler motor size to reduce weight and facilitate incorporation inside the robot.
- Additional ideas such as inclusion of a shock absorber were left out.

In designing the new dribbler subsystem we identified those factors and variables that affect performance. A statistical design was made to distinguish the effects caused by different environment factors. We chose a bar material that generates enough friction over the ball and easily controlled by the motor velocity-torque relationship.

We define dribbler control on the ball as "the ability of the dribbler to catch the ball, dribble it (hold it) and set it free when so desired". Thus, we identified three types of responses: "catch with dribble", "catch with no dribble" and "no catch".

- In *Catch with dribble* the ball impacts the bar without bouncing off. The ball "sticks" under the bar due to the dribbler rotation.
- In *Catch with no dribble* the ball impacts the bar without bouncing off. Although the ball "stays" under the bar, it is not sticking lacking full dribble control. In other words, the dribbler does not manage to keep the ball rotating close to the dribbler.
- In *No catch* the ball impacts the bar and bounces off with absolutely no control over the ball.

To proceed with experimentation we specified objectives and identified relevant response and control variables as described by the guide sheet shown in Table I.

TABLE I
GUIDE SHEET

Eagle Knights Dribbler subsystem study
Objective of the experiment: to better control the ball, quantify the effect of the bar by varying the distance and directions of the ball impacting the bar in the dribbler.
Relevant issues about response and control variables: • **Theoretical relationships**: a change in the material of the bar can generate a better control over the ball. • **Experience**: This is a third design of the dribbler subsystem consequently its function is known and we can identify what problems need to be satisfied. • **Previous Experiment**: Lack of systematization in the past.
The result of this experiment will be used to determine the best material to build the bar while specifying appropriate control variable values.

Statistical design of experiments refers to the process of planning an experimenting in a suitable way to obtain data that can be analyzed by statistics methods [7]. When we consider the factors that can influence the performance of a process or system, those factors can be rated as potential factors or nuisance factors. The potential factors are those that the experimenter may want to modify in the experiment. Since there may be multiple potential design factors there is a need for some form of classification [8]. Some of these factors are considered "held-constant factors" while other ones are termed "nuisance factors". In Figure 11 we show a Venn diagram that can be used to help select and prioritize among candidate factors [9]. The diagram shows those factors that can affect the response variable in three main ways: magnitude of influence on response variable, degree of controllability and measurability, e.g. precision.

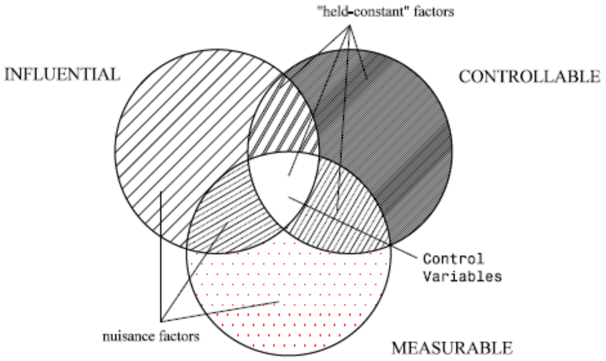

Fig. 11. A Venn diagram showing three categories of factors affecting responses from control variable.

The *experimental factors* or *control variables* are those factors that can be quantified, derived and can influence the experiment as: battery voltage, bar height, diameter of the bar and depth of ball inside the robot. In Table II we show the values assigned to these factors. The battery voltage driving the motor is held at 7.4 volts; the ball distance within the robot is chosen to comply with rule restrictions where at most a ¼ of the ball may be inside the robot; the bar height is set accordingly to 1.075 cm, a quarter of ball diameter (43 mm is total ball diameter); and bar diameter is set to 1.5 cm. This last factor is due to current bar diameter used in the robot.

TABLE II
CONTROL VARIABLES

Factor	Value
Battery voltage	7.4 volts
Ball distance within robot	¼ of ball diameter
Bar height	1.075 cm
Bar diameter	1.5 cm

Held-constant factors are those controllable factors whose effects are not of interest in the experiments. One held-constant factor identified is the type of motor as shown in Table III.

TABLE III
HELD CONSTANT FACTORS

Factor	Value
Motor type	Faulhaber Motor

Nuisance factors are not controllable, and have no primary interest in the experiments. This is because the process varies over time, experimental conditions vary over time, some variations are innocuous, and some are pernicious, such as field, bar temperature and impact force of the ball. Table IV describes nuisance factors for experimentation, including field surface, motor vibration, bar temperature and force of ball impact.

TABLE IV
NUISANCE FACTORS

Factor	Strategy
Field surface	Test dribbler in different zones of the field
Motor vibration	Vary dribbler screwing mechanisms
Bar temperature	Add delay between experiments
Force of ball impact	Vary impact force from ball

To quantify response variables we employ an "apparent response" called "Quality Characteristic" (QC) describing the portion of time the response is either "catch with dribble", "catch with no dribble" and "no catch".

IV. EXPERIMENTS AND RESULTS

In order to better understand the factors described in the Section II affecting dribbler response to control variables, we designed an experimentation scenario consisting of a launch pad directing a ball manually dropped from the pad into the dribbler as shown in Figure 12. We do not consider ball friction in the ramp since it is kept constant throughout the experiment due to the golf ball weighing 46 gr. We also try to keep ball acceleration and resulting force constant by simply letting the ball drop.

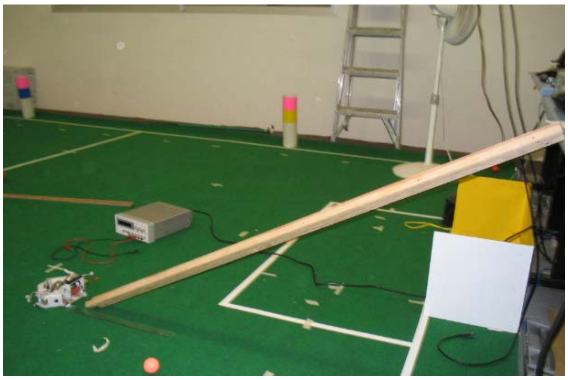

Fig. 12. Dribbler prototype consisting of a launch pad where the ball is manually dropped. The launch pad directs the ball into the robot dribbler.

The specifics of the ramp experiment are described in Figure 13. Three ramp positions are controlled, the height *h* at its extreme, the distance *d* to the robot, and the rotation angle τ with respect to the robot.

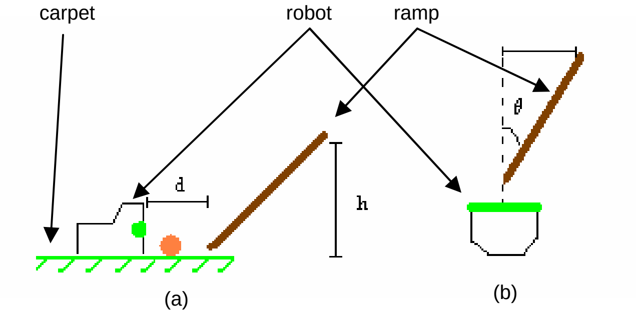

Fig. 13. Experiment Setup. Three ramp positions are controlled, the height *h* at its extreme, the distance *d* to the robot, and the rotation angle τ with respect to the robot.

To validate QC we use a *factorial design* with three factors and three levels (values) indicated by 3^3. In general, a factorial design involves two or more factors, each with two or more levels. A *treatment* is defined as combination of levels for each factor. In a factorial experiment, all possible combinations of factors, i.e. all treatments, are represented for each complete replication of the experiment. The number of treatments is equal to the product of the number of factor levels and can therefore become large when either the factors or the levels are many [10].

In Table V we show the levels that are used for the different factors described in Figure 13. In a 3^k design, it is common to indicate the levels as *low*, *medium* and *high* and to label them with –1, 0 and +1, respectively. The three factors, height ***h***, distance ***d***, and angle $\boldsymbol{\theta}$, shown in Table V were chosen by criterion of the experimenter and are expected to provide some meaningful range of responses. Each of the factors was studied at three levels corresponding to a 3 x 3 x 3 arrangement or 3^3 factorial design.

TABLE V
FACTORS WITH LEVELS

Factors	Notation	Levels		
		-1	0	+1
height	***h***	30 cm	45 cm	60 cm
distance	***d***	35 cm	45 cm	55 cm
angle	$\boldsymbol{\theta}$	0°	40°	55°

The corresponding 27 formulations are shown in Table VI with factors levels coded by –1, 0 and +1, respectively. For example a run using the lower measure of ***h***, the higher measure of ***d*** and the lower measure of $\boldsymbol{\theta}$ would be coded as –1, +1, and –1 (run 7). In the first column –1, 0 and +1 are alternated, and so on for the other columns.

TABLE VI
A 3^3 FACTORIAL DESIGN

Formulation	Factor		
	h	***d***	$\boldsymbol{\theta}$
1	-1	-1	-1
2	0	-1	-1
3	+1	-1	-1
4	-1	0	-1
5	0	0	-1
6	+1	0	-1
7	-1	+1	-1
8	0	+1	-1
9	+1	+1	-1
10	-1	-1	0
11	0	-1	0
12	+1	-1	0
13	-1	0	0
14	0	0	0
15	+1	0	0
16	-1	+1	0
17	0	+1	0
18	+1	+1	0
19	-1	-1	+1
20	0	-1	+1
21	+1	-1	+1
22	-1	0	+1
23	0	0	+1
24	+1	0	+1
25	-1	+1	+1
26	0	+1	+1
27	+1	+1	+1

As shown in Figure 14, the 27 factor combinations described in Table V can be conveniently represented geometrically as vertices of a cube. The 27 factors combinations can be identified by 27 points whose coordinates are (-1,-1,-1), (+1,-1,-1)….,(+1,+1,+1).

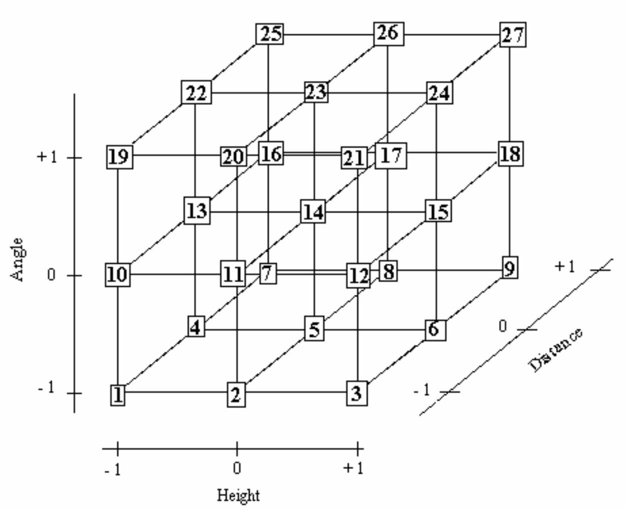

Fig. 14. A cube with 27 point of interest in correspondence to Table V.

In order to run the experiments and to avoid a bias in the results the order of experimentation can be randomized.

TABLE VII
EXPERIMENTAL DRIBBLER RESPONSES

Formulation	Experiment order	Catch & dribble	No catch	Catch no dribble
1	2	30	0	0
2	23	30	0	0
3	5	25	5	0
4	3	30	0	0
5	15	1	20	9
6	27	24	3	3
7	6	29	1	0
8	21	15	2	13
9	11	1	17	12
10	12	20	1	9
11	9	3	5	22
12	22	17	8	5
13	8	21	0	9
14	16	2	8	20
15	7	10	15	5
16	20	25	0	5
17	10	7	7	16
18	14	0	19	11
19	4	20	0	10
20	24	24	1	5
21	19	1	17	12
22	25	30	0	0
23	1	0	18	12
24	26	14	9	7
25	13	12	5	13
26	17	4	11	15
27	18	0	30	0

In order to determine the value of QC we made 27 runs, and in each run we dropped the ball 30 times against the bar according to the order of experimentation. Table VII shows the sequence of formulation and experimentation (randomized), and the results obtained for each control variable in the experiment. Figure 15 shows schematically the results obtained in Table VII.

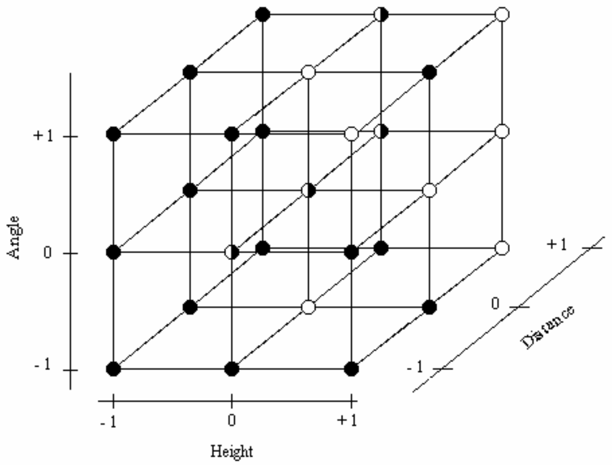

Fig. 15. Experimental layout and observed coded responses. Filled circles represent cases where the ball was caught and dribbled; empty circles represent those cases where the ball was not caught; otherwise half filled circles represent balls caught and not dribbled.

Circles drawn at the vertices represent the type of observed response. Black circles represent cases where the ball was completely caught and dribbled; empty circles represent that the most of shots were not caught and half black circles indicate that most of the shots were caught but not dribbled. It is apparent in the figure that the dribbler performed better at lower heights, distances and angles.

The point within the circle marked by the arrow in Figure 16 can be read as a low (-1), medium (0) and medium (0), height, distance and angle combination, respectively. This corresponds to test values of 30, 45 and 40 resulting in the most shots held as represented by the black circle.

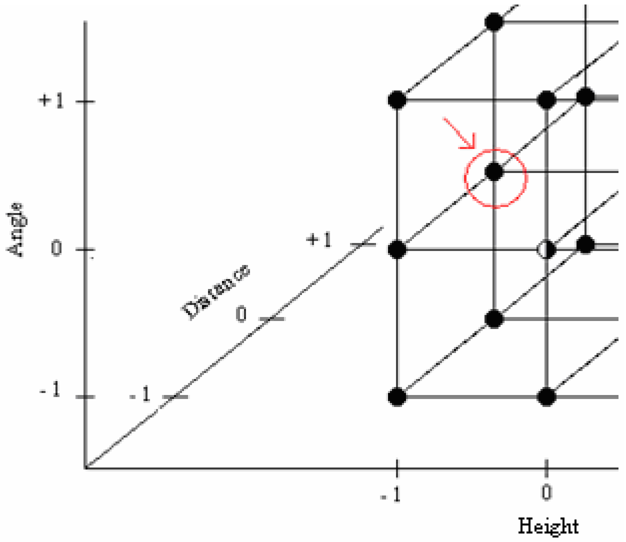

Fig. 16. Locating a particular response corresponding to height -1, distance 0 and angle 0.

In the next figures we show graph for different results. Figure 17 shows balls caught (with dribble) versus ramp height. Note that better results are obtained for lower ramp heights as expected. This results from lower ball acceleration and forces on the bar.

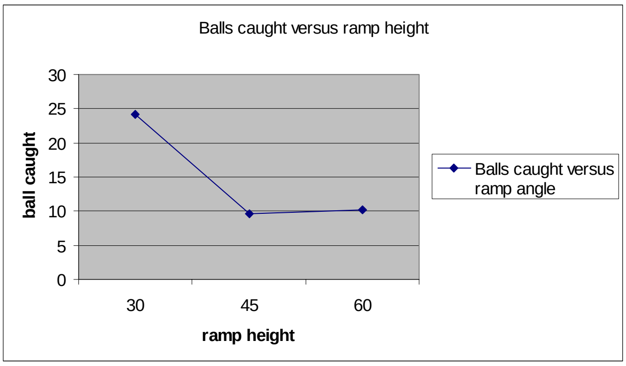

Fig. 17. Ball caught versus ramp height.

Figure 18 shows balls caught (with dribble) versus ramp distance. Note that better results are obtained for lower ramp distances.

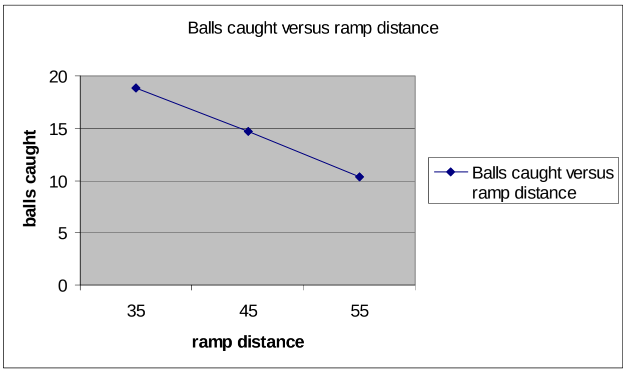

Fig. 18. Ball caught versus ramp distance.

Figure 19 shows balls caught (with dribble) versus ramp angle. Note that better results are obtained at 0 degrees.

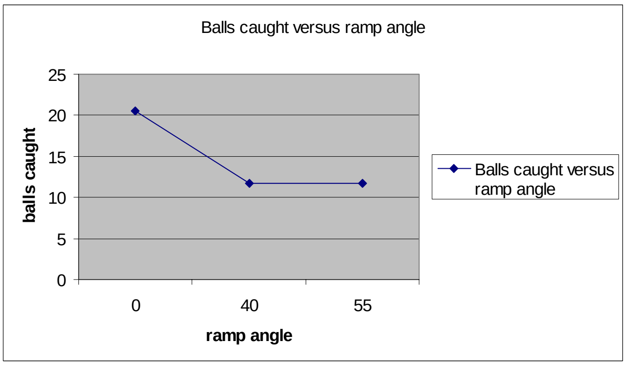

Fig. 19. Ball caught versus ramp angle.

Finally, the EK 2006 robot and dribbler are shown in Figure 20.

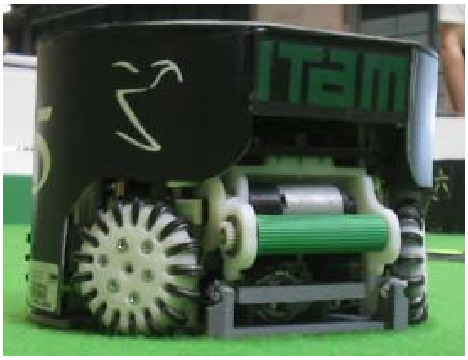

Fig. 20. EK SSL Robot 2006 showing latest dribbler design.

V. CONCLUSIONS

The paper presented the design of the dribbler system for the Eagle Knights 2006 RoboCup Small-Size robots. We have described the mechanics of our particular design and contrasted it to previous EK generations and to other teams. Experiments were performed to help understand the effect of a number of control variables on dribbler response, in particular to catch the ball and dribble it, catch the ball without dribble it and having the ball bounce off the dribbler.

We present experimentation results from a set of tests using a ramp to drop a ball into the dribbler in evaluating different control variables and responses. Although results where somewhat limited, they demonstrated the advantages of having well defined experiment setting with a small set of control variables.

Outside of the laboratory, we tested the new dribbler in Robocup 2006 celebrated in Bremen, Germany. The dribbler it performed better than in previous years although there is room for improvement.

As part of our future plans we are developing a more robust dribbler design while most importantly extending the experimentation framework developed for this work. We plan to experiment with additional materials including soft and stiff rubbers as well as test different bar diameters and positioning with respect to the floor and the robot itself. We are analyzing the inclusion of shock absorber among other extensions.

As discussed in Box, Hunter & Hunter [11], experimentation catalyzes the generation of knowledge.

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