TO: PROFESSOR JOHN T. WEN

FROM: TEAM 2: [Names]

SUBJECT: CONTROL SYSTEM DESIGN – CONCEPTUAL DESIGN

DATE: 1/28/2004

CC:

Executive Summary

The *goal of this project* is to develop a ball-on-plate balancing system, *capable of controlling the position of the ball on the plate for both static positions as well as along smooth paths.*

What is the goal?
What must your design be able to do?

We intend that the initially horizontal plate will be tilted along the two horizontal axes in order to control the position of the ball. Each tilting axis will be operated on by an electric motor. Each motor will be controlled using software, with a minimum of position feedback for control.

How will the system work?

The system will be capable of tilting the plate in such a way as to move the ball to any point within the grid coordinate system formed by the two horizontal axes. The system will also be capable of causing the ball to follow an equation of any line lying in that plane.

Should any disturbance change the location of the ball on the plate, the *system will be able to quickly correct* for this disturbance, returning the ball to its intended location or path. In addition, we intend for the system to have a minimal amount of steady state error and a low amount of overshoot when repositioning the ball on the plate.

What difficulties or challenges do you anticipate?
How will the system respond to difficulties?

A related *system created by a mechatronics team including Professor Kevin Craig* of Rensselaer Polytechnic Institute was created in the past. We intend to improve on the performance and capabilities of that system. While that system was quite functional, *only a slow movement of the ball was possible and it possessed some obvious overshoot and imprecision problems when performing certain tasks*.

What previous work has been done?

What are limitations of that previous work?

Specifications

The system will have the following specifications based on some general estimations and rough calculations for desired performance:

- Range of Motion
    - *The plate will tilt* $\pm 35^\circ$ *about each of the two horizontal axes*
    - Estimating vertical displacement to be four inches at a position five inches from the origin (center) of the plate, *this value was calculated as the* $\tan^{-1}(4/5) = 38.65^\circ$
- Accuracy
    - Due to the dynamics of the ball and plate system, *plate positioning error magnifies the amount of error* in ball positioning. Therefore, *high positioning accuracy in the plate axes will reduce error* in ball placement on the plate surface.
    - Ideally, the ball will be positioned on the plate with less than two percent error over the total dimensions of the plate.

What specification do you estimate that the design must meet?

What basis do you have for this estimation?

What challenges do you anticipate?

How will you meet these challenges?

[The authors of this memo go on to establish specifications re speed, payload, noise tolerance, and cost]

Constraints and Past System Selection

Working from the *base pan-tilt system*, several *modifications* will need to be made to the physical system to allow us to implement a ball on plate system. The stock system will have to be disassembled, and a larger central yoke installed to accommodate our touchpad sensor. This increased size will also necessitate a new motor bracket, as well as a longer tilt axis control arms. To make things easier, a new tilt axis will have to be milled to allow the rotation of axis of the plate pass through its center of mass.

What system will you use?
How will the system need to be modified?

In light of these changes and the aforementioned system specifications, *the ball plate system will require at the very least a high torque base motor* capable of at least our 1.35 radians/sec speed, perhaps more if we determine that speed to be insufficient for proper control. *The requirement comes from the gravity loading placed* on the pan axis. *Unlike other projects* where the pan axis is placed vertically and therefore has zero gravity loading, the ball on plate system has a horizontal pan axis. This magnifies the torque demands placed on the motor and requires a motor capable of supplying not only significant torque, but torque at a rotational speed fast enough to control our system.

What do requirements do you estimate that the system will have to meet?

What is the rationale for your estimation?

How does your project compare with other projects?

Another constraint is the complexity of our system. Positioning errors in the tilt systems magnify any errors in the final position of the ball. A high degree of accuracy is therefore needed, which might need require more precision than is available in the standard encoders available in the stock kit. This will hopefully greatly reduce the possible final error in the system.

With regard to these constraints, it makes the most sense for our system to respectfully request *the Group 5 system*. Its *combination of high torque/high speed motors and high precision encoders* will give us the greatest chance of developing a complete system with high performance and accuracy. A *second choice* might be Group 7 with its high torque motors. Despite its high internal gear reduction, changes to the external gearing could make it capable of driving our system at sufficient speed. *A final choice* could be any of the remaining systems, but with a swap to a high torque motor from either Group 5 or Group 7. The high torque is a necessity to drive our plate due to the gravity loading, but a large motor is definitely not required for the secondary tilt axis. In fact, the weight of a second large motor might hamper our performance.

Which system are you requesting and what features make it appropriate for your project?

Are there alternative systems?

Design Approach

Modeling

Based on our estimated design specifications, a model for the ball-on-plate balancing system can be derived. *Due to the complexity of the problem, a non-linear model must be considered*, and coupling between the pan and tilt axes could come into effect. In order to simplify the control design, the system must be linearized about an operating point [4]

What model do you intend to use and why?

$$(\theta,\dot{\theta}) = (\theta_d,0)$$

It may be possible to further simplify the model by treating the system as fully decoupled. By doing this, the system may be modeled as two independent links. Friction terms will be experimentally measured. The payload should be modeled as the complete secondary system, i.e. the tilt motor, platform, ball, etc. Since the system will be mounted horizontally, gravity loading from the entire secondary system will be felt by the base motor. See the attached Solidworks model for a visual explanation.

How will you need to modify the model?

Control System

Due to both the complexity of the project goal, and the team's interests, we feel as though *a full state-feedback control system would be best. This should allow for very accurate control of both the ball's position and velocity by pole placement.* For the tentative* state vector: [5]

What sort of system will you need? Why do you need that system?

Formula

the controller would be of the form:

Formula here The state vector contains state variables for both the position and velocity of the ball, as well as the position and velocity of the plate. K represents a gain matrix whose elements are gains for each of the state variables. Discussions with the course TA, Ben Potsaid, led to the idea of *using an observer design since we can only directly measure the position, and not velocity. Using finite difference and/or washout filter methods may produce inaccuracy*. The observer design would be of *the form:* *Formula here*	*What sort of design do you intend to use?* *What is your rationale for using this sort of design?* *What form will the design take?*
The added term represents the output injection where L is a column vector designed so that the observer error: *Formula here*	
converges to zero. *An additional method to consider* would be the use of optimal control to minimize state transitions, though *this may be beyond the scope of both our skills, and time allowance*.	*Is there an additional method?* *What might make this alternative undesirable?*
Sensing	
In order to produce an error signal for the control input, we must know the location of the ball in (x,y) coordinates. *Two possibilities were considered,* one of which was almost immediately dismissed.	*What possibilities did you consider and why?*
The first idea involved the use of an overhead camera to track the position of the ball. This would require a fairly high frame-rate, which normally would not be a problem, however since we are trying to implement a real-time control system, we may only be able to obtain a sampling frequency of 1-2Hz which would be inadequate for accurate positioning. The use of a camera would also require additional image processing to occur.	*Why did you discard one possibility?*
Our desired solution is to use a touch-sensitive pad to measure ball location. The team has acquired a 10.4" diagonal Dynapro 95640 4-wire resistive touchpad. The screen's total outside dimensions are 6.75X 0.082." In order to accommodate this screen, a larger yoke, motor mounting plate, and tilt shaft must be made. See the attached Solidworks model.	*What system did you choose*
The touchpad acts as a large resistor. When a force is applied to the surface, the resistance is altered. A controller is sold with the touchpad to interpret the output voltage in terms of (x,y) position. However, we think we can use the available A?D converter to do this without the supplied controller. This will avoid the use of vender-	*How does the system work?*

supplied drivers, which will add complexity to our software design. Due to the glass surface of the touchpad, *a rubber membrane may have to be placed over the touchpad* to increase friction, and keep the ball from sliding. This design was used in Prof. Craig's ball-on-plate system [1] and seemed to work well, though it requires a larger ball to activate the screen.	*How might the system have to be modified?*
Challenges	
Several challenges in the design and construction of this system can be foreseen. In order to construct the physical system it will be necessary to machine several metal parts….	*What challenge do you anticipate?*
Finally, the control problem itself will be a significant challenge. Currently we intend to design the system as two uncoupled links….	*What other challenges do you anticipate and how do you intend to meet them?*