Universidade do Porto Faculdade de Engenharia FEUP	**Faculdade de Engenharia da Universidade do Porto** Licenciatura em Engenharia Informática e Computação **Robótica – Disciplina Opcional do 4º Ano** **Exame de Recurso**		**Duração: 3h00m**
Docentes:	**Eugénio da Costa Oliveira e Luís Paulo Reis**	**Data:**	**12/07/2004**
Nome:			

NAVEGAÇÃO E CONTROLO EM ROBÓTICA

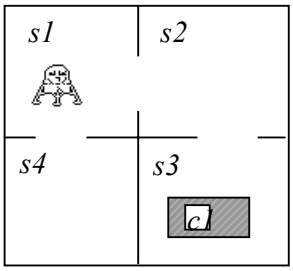
1) Explique a expressão que define a função de coordenação de um Robô.

2) Arquitecturas de Controlo:
   - **a-** Na arquitectura de sub-assunção, qual é a estratégia de controlo?
   - **b-** Nomeie e explique duas arquitecturas de controlo cooperativas
   - **c-** Explique a arquitectura BDI para um robô que se desloca em uma oficina transportando, a pedido, peças entre postos de trabalho que o solicitem.

3) O que é um diagrama de Voronoi, quais as suas vantagens e desvantagens?

PLANEAMENTO EM ROBÓTICA

4) Considere o mundo definido na figura seguinte:



Um robô move-se de uma sala ***Sx*** para outra sala ***Sy*** através de uma porta ***P*** (**atravessar(P,Sx,Sy)**). O robô pode transportar uma caixa ***C*** de uma sala ***Sx*** para outra sala ***Sy*** (**empurrar(C,P,Sx,Sy)**). O robô pode retirar (pousando no chão) uma caixa **C** de cima de um objecto **O** (**retirar(C,O)**).

a) Especifique as listas associadas aos operadores descritos (atravessar, empurrar e retirar).

b) Exemplifique o funcionamento de um planeador não linear, quando o mundo se encontra no estado representado na figura:

na_sala(rob,s1).
caixa(c1).
em(mesa,c1).
na_sala(mesa,s3).
liga(p1,s1,s2).
liga(p2,s2,s3).
liga(p3,s1,s4)

e se prentende atingir o estado final:

na_sala(c1,s2).

Descreva a árvore das possibilidades gerada pelo algoritmo de planeamento não linear (do nível 0 ao 3) e explique.

Nota: Responda unicamente a cinco das seis questões seguintes (5a, 5b, 6a, 6b, 7a e 7b):

SIMULAÇÃO EM ROBÓTICA

Tome como base o excerto de código do framework FCP Agent que permite a criação de equipas de futebol robótico simulado que se encontra nas páginas anexas. Suponha ainda que dispõe das funções *OpponentPos(Num)* e *TeammatePos(Num)* que retornam respectivamente as posições dos oponentes e companheiros de equipa no campo. Apresente as alterações de código que permitem implementar:

5a) Uma estratégia simples de defesa em que: se a bola estiver dentro da própria área todos os jogadores que também estejam dentro da área ou consigam interceptar a bola em menos de 10 ciclos, tentam interceptar a bola. Se a bola estiver fora da área mas a menos de 30 metros do centro da própria baliza, só o jogador mais rápido a interceptar e os jogadores que estejam atrás da linha da bola (segundo o eixo dos xx) desde que demorem menos que 10 ciclos é que tentam interceptar a bola. Caso contrário, interceptam a bola o jogador mais rápido e todos os jogadores que interceptem a bola em menos de 10 ciclos e sejam mais rápidos do que o adversário mais rápido. **(2 Val.)**

5b) Um algoritmo de troca dinâmica de posições em que dois jogadores trocam de posição caso a distância às suas posições estratégicas em caso de troca seja menor do que a distância às suas posições estratégicas sem efectuar a troca. Considere também que para se efectuar a troca, o tempo de jogo tem de ser múltiplo de um dos números dos jogadores envolvidos e que os defesas centrais (números 3 e 4) e o guarda-redes não efectuam trocas. **(2 Val.)**

PLATAFORMAS ROBÓTICAS

6a) Explique resumidamente mas com exemplos concretos, quais as vantagens e desvantagens de programar em RCODE relativamente ao OPEN-R SDK. Que programas só conseguiria fazer em RCODE? Que programas só conseguiria fazer em OPEN-R SDK? Construa um programa simples em RCODE para um robô ERS210A que faça o seguinte: Se o robô detectar um obstáculo em frente (a menos de 60 cm), roda aleatoriamente para a esquerda ou direita até não detectar obstáculo. Se ouvir um dos "AiboSounds" ou conseguir localizar a bola cor-de-rosa, então ele deita-se. Caso contrário, desloca-se efectuando a seguinte sequência de acções: andar em frente 10 segundos, rodar à esquerda 2 segundos. Caso seja pressionado o interruptor das costas ou da cabeça, o robô deve sentar-se e não fazer nada até que o mesmo interruptor seja novamente pressionado. **(2 Val.)**

6b) Baseado no exemplo anexo "Ball Tracking Head" do OPEN-R SDK, explique detalhadamente como é que o robô efectua o processamento e análise de imagem de forma a detectar a posição da bola e virar o pescoço para lá centrando a bola na imagem. Explique, apresentando as alterações que teria de executar no código, como alteraria o programa de forma a unicamente detectar um quadrado (aproximado) cor-de-rosa em vez de detectar formas esféricas? **(2 Val.)**

COMPETIÇÕES ROBÓTICA

7a) Descreva sucintamente as diferenças na complexidade do hardware e software entre um robô para participar nas seguintes competições robóticas nacionais: Condução Autónoma do Festival Nacional de Robótica (FNR), Seguimento de Pista do FNR, Micro-Rato e Robô Bombeiro (usando todas as regras). Em que competições lhe parece possível utilizar o mesmo robô (com alterações mínimas de hardware)? Em que competições lhe parece possível a um robô ERS210 participar? **(2 Val.)**

7b) Compare as ligas de simulação 2D e 3D, robôs pequenos, robôs médios, robôs com pernas e simulação de resgate e salvamento do campeonato do mundo de Futebol Robótico – RoboCup a nível de **(2 Val.)**:

a) Capacidades de acção dos robôs e influência dos "low-level-skills" no desempenho da equipa;

b) Facilidade de utilização de posicionamento estratégico e troca dinâmica de posições nas equipas (no caso do Rescue refira-se como exemplo aos bombeiros);

MemPortugal.C

```
#define NUM_FORM 1      //Formations (like 433Open, 422, etc)
#define NUM_PLTYPES 5   //Player Types

void Portugal1Info::Initialize()
{
  ReadFormations();
  SetGlobalFormation(0);
  for(int i=1;i<=SP_team_size;i++) FM_Positioning[i]=i;
}

/*****************************************************************************************/
/******************************** Formation Analysis *************************************/
/*****************************************************************************************/
void Portugal1Info::ReadFormations()
{
  int i,t,k;
  FILE *fich;
  char line1[512], *str;
  if ((fich=fopen("formations.conf","r"))==NULL) {
       fprintf(stderr,"Formation Configuration File does not Exist!\n"); return; }

  for(i=0; i < NUM_FORM; i++) {
        fgets(line1, 200, fich); fgets(line1, 30, fich);
        fgets(line1, 200, fich); str = &line1[0];
        for(t=1; t<=11; t++) FM_Position[i][0][t].x = get_float(&str);
        fgets(line1, 200, fich); str = &line1[0];
        for(t=1; t<=11; t++) FM_Position[i][0][t].y = get_float(&str);
        fgets(line1, 200, fich); str = &line1[0];
        for(t=1; t<=11; t++) FM_PlayerType[i][t] = get_int(&str);
        fgets(line1, 200, fich); str = &line1[0];
        for(k=0; k<NUM_PLTYPES; k++) FM_Attraction[i][k].x = get_float(&str);
        fgets(line1, 200, fich); str = &line1[0];
        for(k=0; k<NUM_PLTYPES; k++) FM_Attraction[i][k].y = get_float(&str);
        fgets(line1, 200, fich); str = &line1[0];
        for(k=0; k<NUM_PLTYPES; k++) FM_BehindBall[i][k] = get_int(&str);
        fgets(line1, 200, fich); str = &line1[0];
        for(k=0; k<NUM_PLTYPES; k++) FM_MinX[i][k] = get_float(&str);
        fgets(line1, 200, fich); str = &line1[0];
        for(k=0; k<NUM_PLTYPES; k++) FM_MaxX[i][k] = get_float(&str);
  }
  fclose(fich);
}

// Why not use situations? What should be the tactic and formation for each situation?
// How to define different player types?
void Portugal1Info::DecideFormation(void)
{
    SetGlobalFormation(0);
}

/*****************************************************************************************/
/*******************************  Communication  *****************************************/
/*****************************************************************************************/
// Only players that think they have important things to say, should talk!
void Portugal1Info::DoCommunication(void)   // Communicate World State
{
    if (ClockStopped || BallVelocityValid()>=0.9 && (CurrentTime.t+2) % 2 == 0 )
       send_game_status();  // Send World State
}

void Portugal1Info::say_something(char *message)   // Say Message
{
  SayAction.type = CMD_say;
  SayAction.time = CurrentTime;
  sprintf(SayAction.command, "(say %s)",message);
}

// Why not communicate the players positions and velocities and useful events?
void Portugal1Info::send_game_status()   // Send Game Status
{
  char str[512], str_aux[512];
  if(!MyConf()) return;

  sprintf(str_aux,"world_status %1.2f %1.2f ", MyX(),MyY());
  strcpy(str,str_aux);
  if (BallPositionValid()) {
    sprintf(str_aux,"1 %1.2f %1.2f %1.2f ",BallPositionValid(), BallX(),BallY());
    strcat(str,str_aux);
    if (BallVelocityValid())
```

```
      sprintf(str_aux,"1 %1.2f %1.2f %1.2f ",BallVelocityValid(),
                      BallAbsoluteVelocity().x, BallAbsoluteVelocity().y);
    else sprintf(str_aux,"0 ");
    strcat(str,str_aux);
  }
  else {
    sprintf(str_aux,"0 ");
    strcat(str,str_aux);
  }
  say_something(str);
}

// To compress and encode this, is a very good idea!
void Portugal1Info::parse_world_status(char *message)   // Parse Game Status
{
  char *str = &message[0];
  float x, y, pivotx, pivoty, conf, vx, vy, vconf;

  get_word(&str);
  pivotx = get_float(&str); pivoty = get_float(&str);
  if (get_int(&str)) { // Ball position
    conf = get_float(&str); x = get_float(&str); y = get_float(&str);
    if (get_int(&str)) { // Ball Velocity
      vconf  = get_float(&str); vx = get_float(&str); vy = get_float(&str);
      HearBall(x,y,conf, vx,vy,vconf,Vector(x-pivotx,y-pivoty).mod(), CurrentTime);
    }
    else HearBall(x,y,conf, Vector(x-pivotx,y-pivoty).mod(), CurrentTime);
  }
}

// To use an online coach may be very useful!
void Portugal1Info::parse_received_message(int direction, char *message)
{
  switch(message[0]) { case 'w': parse_world_status(message); }
}

/*******************************************************************************************/
/************************* Individual Decision Making  *************************************/
/*******************************************************************************************/

// Lots of things to explore here! This is really a basic decision mechanism...
void Portugal1Info::DecideAction(void)   // Individual Decision Making
{
   if(!MyConf() || !BallPositionValid()) {scan_field_with_body(); return;}
   RefreshPositioningMatrix();              // analyses interceptions
   if (BallKickable()) DoBallMove();        // I have the ball? What to do with it?
   else DoPositioning();                    // Go to best Position!
}

// Pass, Forward, Dribble, Hold, Shoot to different places, [Reis and Lau 2001]...
void Portugal1Info::DoBallMove(void)   // Ball Possession: Situation With Ball
{
   smart_kick_hard(AngleToFromBody(Vector(52.5,0.0)), KM_Moderate);  //Shoot to the Goal!
}

// It is not a good idea to always intercept... Sometimes is better to keep the position...
// Think about other ball recovery actions like mark pass lines, mark opponents, cover goal…
void Portugal1Info::DoPositioning(void)   // Ball Recovery and Positioning: Situations Without
ball
{
  if (PO_MyInterc-2<=PO_TeammateInterc && PO_MyInterc<30 || PO_MyInterc<10)
       get_ball();                  // Intercept the Ball
  else DoSBSPPositioning();         // Strategic Position
}

// This is not really SBSP because situations are not considered.
void Portugal1Info::DoSBSPPositioning(void)   // Strategic Situation
{
  go_to_point(SBSPPosition(MyNumber),1.5+fabs(BallX()-MyX())/10.0,PowerConserveStamina());
}

// This is also basic. Reason about the importance of spending stamina at each moment!
float Portugal1Info::PowerConserveStamina(void)  // Stamina Management
{
  if (MyInterceptionAble() &&
     (abs(PO_MyInterc-PO_OpponInterc)<3 || PO_MyInterc<4)) return 100.0;  //Ball is disputed
  if(MyStamina()-150.0<SP_recover_dec_thr*SP_stamina_max)
       return 30.0*(MyRecovery()); // don't loose recovery!
  return 100.0;
}
```

```
// Only basic information included. Why not use interception matrixes
// (with values for all players) and reason using that information.
// Use distances on the reasoning! Use similar structure to Ball Possession information!
void Portugal1Info::RefreshPositioningMatrix()  //Interception Analysis
{
  if (FastestOpponentToBall() != Unum_Unknown) {    // Cycles to ball of fastest opponent
     PO_OpponInterc = OpponentInterceptionNumberCycles(FastestOpponentToBall());}
  else { PO_OpponInterc = 150; }
  if (FastestTeammateToBall() != Unum_Unknown) {    // Cycles to ball of fastest teammate
     PO_TeammateInterc = TeammateInterceptionNumberCycles(FastestTeammateToBall());}
  else { PO_TeammateInterc = 200; }
  if (MyInterceptionAble()) {                       // My number of cycles to ball
     PO_MyInterc = MyInterceptionNumberCycles(); }
  else { PO_MyInterc = 250; }
}

/*****************************************************************************************/
/******************** SBSP - Situation Based Strategic Positioning  ********************/
/*****************************************************************************************/

// Calculates the Strategic Positioning using a very simple SBSP implementation
// Improve this using situations, attractions by points or lines in some situations, etc.
Vector Portugal1Info::SBSPPosition(int t)
{
  Vector Position = FormationGetPosition(t);
  float FactorX = FormationGetAttraction(t).x;
  float FactorY = FormationGetAttraction(t).y;
  Position.x = Position.x + BallX() * FactorX;
  Position.y = Position.y + BallY() * FactorY;
  if (fabs(Position.y) > 24.0) Position.y = Position.y - 0.5*FactorY*BallY();
  Position = PositionToOnsidePosition(Position);
  if (FormationGetBehindBall(t) && BallX() < Position.x) Position.x = BallX();
  if (Position.x > FormationGetMaxX(t)) Position.x = FormationGetMaxX(t);
  if (Position.x < FormationGetMinX(t)) Position.x = FormationGetMinX(t);
  return Position;
}

/*****************************************************************************************/
/************************  Normal Player Central Module  *****************************/
/*****************************************************************************************/

// This is a very simple player. Use different things like DPRE - Dynamic Positioning and Role
// Exchange that enables the players to switch their positionings in a given formation or
// SLM - Strategic Looking that enables the players to look at the best spot in the field
void Portugal1Info::NormalPlayer()
{
   static int players_moved = FALSE;
   if (PlayMode==PM_Before_Kick_Off || PlayMode==PM_Half_Time || PlayMode==PM_Extended_Time)
       if (players_moved) return;
       else {
            players_moved = TRUE;
            if (FormationGetPosition(MyNumber).x < 0.0) move(FormationGetPosition(MyNumber));
            else move(-1.0,FormationGetPosition(MyNumber).y);
            return;
       }
   players_moved = FALSE;

   DecideFormation();         // Formation Analysis
   DoCommunication();         // Communicate
   DecideAction();            // Individual Decision Making
}
```

Formations.Conf

```
0 // Formation 0 ********************************************************
-45.0 -13.0 -14.0 -14.0 -13.0  -5.0   0.0  0.0  10.0  15.0  10.0   //posx
  0.0  16.0   5.0  -5.0 -16.0   0.5  10.0 -10.0  -0.5  20.0 -20.0   //posy
 0 2 1 1 2 2 2 2 3 3 3    // PT_GOA PT_DEF PT_MID...  //Type
 0.1  0.5  0.5  0.5  0.5        //AttractionX
 0.1  0.25 0.25 0.25 0.25       //AttractionY
   1  1    0    0    0          //BehindBall
-52.5 -45.0 -45.0 -30.0 -45.0   //MinX
-30.0   0.0  35.0  42.0  42.0   //MaxX
1  // Formation 1 ********************************************************
-45.0 -11.0 -12.0 -12.0 -11.0   3.0  -4.0  -4.0   3.0  15.0  15.0   //posx
  0.0  17.0   6.0  -6.0 -17.0  25.0  10.0 -10.0 -25.0   8.0 -10.0   //posy
 0 2 1 1 2 2 2 2 2 3 3    // PT_GOA PT_DEF PT_MID...  //Type
 0.1  0.5  0.5  0.5  0.5        //AttractionX
 0.1  0.25 0.25 0.25 0.25       //AttractionY
   1  1    0    0    0          //BehindBall
-52.5 -45.0 -45.0 -30.0 -45.0   //MinX
-30.0   0.0  35.0  42.0  42.0   //MaxX
```

BallTrackingHead.h

```
#include <OPENR/OObject.h>
#include <OPENR/OSubject.h>
#include <OPENR/OObserver.h>
#include <OPENR/ODataFormats.h>
#include <OPENR/OFbkImage.h>
#include <BallTrackingHeadData.h>
#include "def.h"

enum BallTrackingHeadState { BTHS_IDLE, BTHS_START, BTHS_HEAD_ZERO_POS,
    BTHS_LEGS_SLEEPING, BTHS_SEARCHING_BALL, BTHS_TRACKING_BALL};

static const char* const FBK_LOCATOR = "PRM:/r1/c1/c2/c3/i1-FbkImageSensor:F1";
static const char* const JOINT_LOCATOR[] = {
    "PRM:/r1/c1-Joint2:j1",     // HEAD TILT
    "PRM:/r1/c1/c2-Joint2:j2"   // HEAD PAN
};

class BallTrackingHead : public OObject {
public:
    BallTrackingHead();
    virtual ~BallTrackingHead() {}

    OSubject*  subject[numOfSubject];
    OObserver* observer[numOfObserver];

    virtual OStatus DoInit   (const OSystemEvent& event);
    virtual OStatus DoStart  (const OSystemEvent& event);
    virtual OStatus DoStop   (const OSystemEvent& event);
    virtual OStatus DoDestroy(const OSystemEvent& event);

    void NotifyImage(const ONotifyEvent& event);
    void NotifySensor(const ONotifyEvent& event);
    void NotifyMovingHeadResult(const ONotifyEvent& event);
    void NotifyMovingLegsResult(const ONotifyEvent& event);
    void NotifyLostFoundSoundResult(const ONotifyEvent& event);

private:
    static const size_t      NUM_COMMAND_VECTOR = 4;
    static const size_t      NUM_SENSOR_VECTOR  = 2;
    static const size_t      NUM_JOINTS         = 2;
    static const size_t      NUM_FRAMES         = 5;
    static const int         TILT_INDEX         = 0;
    static const int         PAN_INDEX          = 1;
    static const byte        BALL_THRESHOLD     = 10;
    static const int         FOUND_THRESHOLD    = 2;
    static const int         LOST_THRESHOLD     = 5;
    static const OCdtChannel BALL_CDT_CHAN      = ocdtCHANNEL0;
    static const double      FIELD_VIEW_H       = 57.6;
    static const double      FIELD_VIEW_V       = 47.8;

    void OpenPrimitives();
    void NewCommandVectorData();
    void PlaySound(BallTrackingHeadCommandType type);

    void SetCdtVectorDataOfPinkBall();
    bool CentroidAndDeltaAngle(const OFbkImage& cdtImage,
              int* xcentroid, int* ycentroid, double* delta_pan, double* delta_pan);

    void InitSensorIndex(OSensorFrameVectorData* sensorVec);
    void GetPanTiltAngle(longword frameNum, double* pan, double* tilt);

    void SearchBall();
    void TrackBall(longword frameNum, double delta_pan, double delta_pan);
    void MoveHead(double s_pan, double s_tilt, double e_pan, double e_tilt,
                  double *r_pan, double *r_tilt, double pan_limit, double tilt_limit);
    void SetJointValue(RCRegion* rgn, int idx, double start, double end);
    RCRegion* FindFreeRegion();

    BallTrackingHeadState   ballTrackingHeadState;
    OPrimitiveID            fbkID;
    OPrimitiveID            jointID[NUM_JOINTS];
    RCRegion*               region[NUM_COMMAND_VECTOR];
    bool                    initSensorIndex;
    int                     sensoridx[NUM_JOINTS];
    list<RCRegion*>         sensorRegions;
    double                  lastRefPan;
    double                  lastRefTilt;
};
```

BallTrackingHead.cc

```
#include <OPENR/OPENRAPI.h>
#include <OPENR/OSyslog.h>
#include <OPENR/core_macro.h>
#include <BallTrackingHeadData.h>
#include "BallTrackingHead.h"

BallTrackingHead::BallTrackingHead() : ballTrackingHeadState(BTHS_IDLE),
                      fbkID(oprimitiveID_UNDEF), initSensorIndex(false),
                      sensorRegions(), lastRefPan(0), lastRefTilt(0)
{
    for (int i = 0; i < NUM_JOINTS; i++) jointID[i] = oprimitiveID_UNDEF;
    for (int i = 0; i < NUM_COMMAND_VECTOR; i++) region[i] = 0;
    for (int i = 0; i < NUM_JOINTS; i++) sensoridx[i] = -1;
}

OStatus  BallTrackingHead::DoInit(const OSystemEvent& event)
{
    OSYSDEBUG(("BallTrackingHead::DoInit()\n"));
    NEW_ALL_SUBJECT_AND_OBSERVER;
    REGISTER_ALL_ENTRY;
    SET_ALL_READY_AND_NOTIFY_ENTRY;

    OpenPrimitives();
    NewCommandVectorData();
    SetCdtVectorDataOfPinkBall();
    return oSUCCESS;
}

OStatus  BallTrackingHead::DoStart(const OSystemEvent& event)
{
    OSYSDEBUG(("BallTrackingHead::DoStart()\n"));
    BallTrackingHeadCommand headcmd(BTHCMD_MOVE_TO_ZERO_POS);
    subject[sbjMovingHead]->SetData(&headcmd, sizeof(headcmd));
    subject[sbjMovingHead]->NotifyObservers();

    BallTrackingHeadCommand legscmd(BTHCMD_MOVE_TO_SLEEPING);
    subject[sbjMovingLegs]->SetData(&legscmd, sizeof(legscmd));
    subject[sbjMovingLegs]->NotifyObservers();

    ballTrackingHeadState = BTHS_START;
    ENABLE_ALL_SUBJECT;
    ASSERT_READY_TO_ALL_OBSERVER;
    return oSUCCESS;
}

OStatus BallTrackingHead::DoStop(const OSystemEvent& event)
{
    OSYSDEBUG(("BallTrackingHead::DoStop()\n"));
    ballTrackingHeadState = BTHS_IDLE;
    DISABLE_ALL_SUBJECT;
    DEASSERT_READY_TO_ALL_OBSERVER;
    return oSUCCESS;
}

OStatus BallTrackingHead::DoDestroy(const OSystemEvent& event)
{
    DELETE_ALL_SUBJECT_AND_OBSERVER;
    return oSUCCESS;
}

void BallTrackingHead::NotifyMovingHeadResult(const ONotifyEvent& event)
{
    OSYSDEBUG(("BallTrackingHead::NotifyMovingHeadResult()\n"));
    if (ballTrackingHeadState == BTHS_IDLE) return; // do nothing

    BallTrackingHeadResult* result = (BallTrackingHeadResult*)event.Data(0);
    if (result->status == BTH_SUCCESS) {
        if (ballTrackingHeadState == BTHS_START) {
            ballTrackingHeadState = BTHS_HEAD_ZERO_POS;
        } else if (ballTrackingHeadState == BTHS_LEGS_SLEEPING) {
            SearchBall();
            ballTrackingHeadState = BTHS_SEARCHING_BALL;
        }
    } else {
        OSYSLOG1((osyslogERROR, "%s : %s %d", "BallTrackingHead::NotifyMovingHeadResult()",
                  "FAILED. result->status", result->status));
    }
    observer[event.ObsIndex()]->AssertReady();
}
```

```
void BallTrackingHead::NotifyMovingLegsResult(const ONotifyEvent& event)
{
    OSYSDEBUG(("BallTrackingHead::NotifyMovingLegsResult()\n"));
    if (ballTrackingHeadState == BTHS_IDLE) return; // do nothing
    BallTrackingHeadResult* result = (BallTrackingHeadResult*)event.Data(0);
    if (result->status == BTH_SUCCESS) {
        if (ballTrackingHeadState == BTHS_START) {
            ballTrackingHeadState = BTHS_LEGS_SLEEPING;
        } else if (ballTrackingHeadState == BTHS_HEAD_ZERO_POS) {
            SearchBall();
            ballTrackingHeadState = BTHS_SEARCHING_BALL;
        }
    } else {
        OSYSLOG1((osyslogERROR, "%s : %s %d", "BallTrackingHead::NotifyMovingLegsResult()",
                  "FAILED. result->status", result->status));
    }
    observer[event.ObsIndex()]->AssertReady();
}

void BallTrackingHead::NotifyLostFoundSoundResult(const ONotifyEvent& event)
{
    OSYSDEBUG(("BallTrackingHead::NotifyLostFoundSoundResult()\n"));
    if (ballTrackingHeadState == BTHS_IDLE) return; // do nothing
    BallTrackingHeadResult* result = (BallTrackingHeadResult*)event.Data(0);
    if (result->status != BTH_SUCCESS) {
        OSYSLOG1((osyslogERROR, "%s : %s %d","BallTrackingHead::NotifyLostFoundSoundResult()",
                  "FAILED. result->status", result->status));
    }
    observer[event.ObsIndex()]->AssertReady();
}

void BallTrackingHead::OpenPrimitives()
{
    OStatus result;
    for (int i = 0; i < NUM_JOINTS; i++) {
        result = OPENR::OpenPrimitive(JOINT_LOCATOR[i], &jointID[i]);
        if (result != oSUCCESS) {
            OSYSLOG1((osyslogERROR, "%s : %s %d", "BallTrackingHead::OpenPrimitives()",
                      "OPENR::OpenPrimitive() FAILED", result));
        }
    }
    result = OPENR::OpenPrimitive(FBK_LOCATOR, &fbkID);
    if (result != oSUCCESS) {
        OSYSLOG1((osyslogERROR, "%s : %s %d", "BallTrackingHead::OpenPrimitives()",
                  "OPENR::OpenPrimitive() FAILED", result));
    }
}

void BallTrackingHead::NewCommandVectorData()
{
    OStatus result;
    MemoryRegionID      cmdVecDataID;
    OCommandVectorData* cmdVecData;
    OCommandInfo*       info;

    for (int i = 0; i < NUM_COMMAND_VECTOR; i++) {
        result = OPENR::NewCommandVectorData(NUM_JOINTS, &cmdVecDataID, &cmdVecData);
        if (result != oSUCCESS) {
            OSYSLOG1((osyslogERROR, "%s : %s %d",  "BallTrackingHead::NewCommandVectorData()",
                      "OPENR::NewCommandVectorData() FAILED", result));
        }

        region[i] = new RCRegion(cmdVecData->vectorInfo.memRegionID,
          cmdVecData->vectorInfo.offset, (void*)cmdVecData, cmdVecData->vectorInfo.totalSize);
        cmdVecData->SetNumData(NUM_JOINTS);

        for (int j = 0; j < NUM_JOINTS; j++) {
            info = cmdVecData->GetInfo(j);
            info->Set(odataJOINT_COMMAND2, jointID[j], NUM_FRAMES);
        }
    }
}

void BallTrackingHead::PlaySound(BallTrackingHeadCommandType type)
{
    OSYSDEBUG(("BallTrackingHead::PlaySound()\n"));
    BallTrackingHeadCommand cmd(type);
    subject[sbjLostFoundSound]->SetData(&cmd, sizeof(cmd));
    subject[sbjLostFoundSound]->NotifyObservers();
}
```

BallTrackingHead_Image.cc

```
#include <OPENR/OPENRAPI.h>
#include <OPENR/OSyslog.h>
#include "BallTrackingHead.h"

void BallTrackingHead::NotifyImage(const ONotifyEvent& event)
{
    static int found = 0;
    static int lost = 0;

    int    xc, yc;              // centroid
    double d_pan, d_tilt;       // delta angle

    if (ballTrackingHeadState == BTHS_IDLE) return; // do nothing

    OFbkImageVectorData* imageVec = (OFbkImageVectorData*)event.Data(0);

    OFbkImageInfo* info = imageVec->GetInfo(ofbkimageLAYER_C);
    byte*          data = imageVec->GetData(ofbkimageLAYER_C);
    OFbkImage cdtImage(info, data, ofbkimageBAND_CDT);

    if (ballTrackingHeadState == BTHS_SEARCHING_BALL) {

        if (cdtImage.ColorFrequency(BALL_CDT_CHAN) >= BALL_THRESHOLD) {
            found++;
        } else {
            found = 0;
            SearchBall();
        }

        if (found == FOUND_THRESHOLD) {
            OSYSPRINT(("### BALL FOUND ### \n"));
            PlaySound(BTHCMD_PLAY_FOUND_SOUND);
            found = 0;
            CentroidAndDeltaAngle(cdtImage, &xc, &yc, &d_pan, &d_tilt);
            TrackBall(info->frameNumber, d_pan, d_tilt);
        }

    } else if (ballTrackingHeadState == BTHS_TRACKING_BALL) {

        if (cdtImage.ColorFrequency(BALL_CDT_CHAN) >= BALL_THRESHOLD) {
            lost = 0;
            CentroidAndDeltaAngle(cdtImage, &xc, &yc, &d_pan, &d_tilt);
            TrackBall(info->frameNumber, d_pan, d_tilt);
        } else {
            lost++;
        }

        if (lost == LOST_THRESHOLD) {
            OSYSPRINT(("### BALL LOST ### \n"));
            PlaySound(BTHCMD_PLAY_LOST_SOUND);
            SearchBall();
            lost = 0;
        }
    }

    observer[event.ObsIndex()]->AssertReady();
}

void BallTrackingHead::SetCdtVectorDataOfPinkBall()
{
    OSYSDEBUG(("BallTrackingHead::SetCdtVectorDataOfPinkBall()\n"));

    OStatus result;
    MemoryRegionID  cdtVecID;
    OCdtVectorData* cdtVec;
    OCdtInfo*       cdt;

    result = OPENR::NewCdtVectorData(&cdtVecID, &cdtVec);
    if (result != oSUCCESS) {
        OSYSLOG1((osyslogERROR, "%s : %s %d", "ImageObserver::SetCdtVectorDataOfPinkBall()",
                  "OPENR::NewCdtVectorData() FAILED", result));
        return;
    }

    cdtVec->SetNumData(1);

    cdt = cdtVec->GetInfo(0);
    cdt->Init(fbkID, BALL_CDT_CHAN);
```

```
    // cdt->Set(Y_segment, Cr_max,  Cr_min, Cb_max, Cb_min)
    cdt->Set( 0, 230, 150, 190, 120);
    cdt->Set( 1, 230, 150, 190, 120);
    cdt->Set( 2, 230, 150, 190, 120);
    cdt->Set( 3, 230, 150, 190, 120);
    cdt->Set( 4, 230, 150, 190, 120);
    cdt->Set( 5, 230, 150, 190, 120);
    cdt->Set( 6, 230, 150, 190, 120);
    cdt->Set( 7, 230, 150, 190, 120);
    cdt->Set( 8, 230, 150, 190, 120);
    cdt->Set( 9, 230, 150, 190, 120);
    cdt->Set(10, 230, 150, 190, 120);
    cdt->Set(11, 230, 150, 190, 120);
    cdt->Set(12, 230, 150, 190, 120);
    cdt->Set(13, 230, 150, 190, 120);
    cdt->Set(14, 230, 150, 190, 120);
    cdt->Set(15, 230, 150, 190, 120);
    cdt->Set(16, 230, 150, 190, 120);
    cdt->Set(17, 230, 150, 190, 120);
    cdt->Set(18, 230, 150, 190, 120);
    cdt->Set(19, 230, 150, 190, 120);
    cdt->Set(20, 230, 160, 190, 120);
    cdt->Set(21, 230, 160, 190, 120);
    cdt->Set(22, 230, 160, 190, 120);
    cdt->Set(23, 230, 160, 190, 120);
    cdt->Set(24, 230, 160, 190, 120);
    cdt->Set(25, 230, 160, 190, 120);
    cdt->Set(26, 230, 160, 190, 120);
    cdt->Set(27, 230, 160, 190, 120);
    cdt->Set(28, 230, 160, 190, 120);
    cdt->Set(29, 230, 160, 190, 120);
    cdt->Set(30, 230, 160, 190, 120);
    cdt->Set(31, 230, 160, 190, 120);

    result = OPENR::SetCdtVectorData(cdtVecID);
    if (result != oSUCCESS) {
        OSYSLOG1((osyslogERROR, "%s : %s %d", "ImageObserver::SetCdtVectorDataOfPinkBall()",
                  "OPENR::SetCdtVectorData() FAILED", result));
    }

    result = OPENR::DeleteCdtVectorData(cdtVecID);
    if (result != oSUCCESS) {
        OSYSLOG1((osyslogERROR, "%s : %s %d", "ImageObserver::SetCdtVectorDataOfPinkBall()",
                  "OPENR::DeleteCdtVectorData() FAILED", result));
    }
}

bool BallTrackingHead::CentroidAndDeltaAngle(const OFbkImage& cdtImage,
     int* xcentroid, int* ycentroid, double* delta_pan, double* delta_tilt)
{
    int w     = cdtImage.Width();
    int h     = cdtImage.Height();
    byte* ptr = cdtImage.Pointer();

    int xsum   = 0;
    int ysum    = 0;
    int npixels = 0;

    // Last line is not used because of TagInfo.
    for (int y = 0; y < h-1; y++) {
        for (int x = 0; x < w; x++) {
            if (*ptr++ & BALL_CDT_CHAN) {
                xsum += x; ysum += y; npixels++;
            }
        }
    }

    if (npixels != 0) {
        *xcentroid  = xsum / npixels;
        *ycentroid  = ysum / npixels;
        *delta_pan  = -1.0 * FIELD_VIEW_H * (*xcentroid - w/2.0) / w;
        *delta_tilt = -1.0 * FIELD_VIEW_V * (*ycentroid - h/2.0) / h;
        return true;
    } else {
        *xcentroid  = 0; *ycentroid  = 0; *delta_pan  = 0.0; *delta_tilt = 0.0;
        return false;
    }
}
```

BallTrackingHead_Joint.cc

```
#include <OPENR/OPENRAPI.h>
#include <OPENR/OUnits.h>
#include <OPENR/OSyslog.h>
#include <OPENR/ODebug.h>
#include "BallTrackingHead.h"

void BallTrackingHead::SearchBall()
{
    static double phase      = 0.0;
    const  double deltaPhase = 0.03;
    const  double amplitude  = 70.0; // degrees

    OSYSDEBUG(("BallTrackingHead::SearchBall()\n"));
    if (ballTrackingHeadState != BTHS_SEARCHING_BALL) {
        ballTrackingHeadState = BTHS_SEARCHING_BALL;
        if (lastRefPan < 0.0) { phase = lastRefPan / amplitude; }
        else { phase = M_PI - lastRefPan / amplitude; }
    }

    const double panDeltaLimit  = deltaPhase * amplitude; // degrees / 32ms
    const double tiltDeltaLimit = 1.0;                    // degrees / 32ms
    double pan  = amplitude * sin(phase);
    double tilt = 0.0;
    phase += deltaPhase;
    MoveHead(lastRefPan, lastRefTilt, pan, tilt, &lastRefPan, &lastRefTilt,
             panDeltaLimit, tiltDeltaLimit );
}

void BallTrackingHead::TrackBall(longword frameNum, double delta_pan, double delta_tilt)
{
    if (ballTrackingHeadState==BTHS_SEARCHING_BALL){ballTrackingHeadState=BTHS_TRACKING_BALL;}
    const double panDeltaLimit  = 5.0; // degrees / 32ms
    const double tiltDeltaLimit = 5.0; // degrees / 32ms
    double pan, tilt;
    GetPanTiltAngle(frameNum, &pan, &tilt);
    MoveHead(lastRefPan, lastRefTilt, pan + delta_pan, tilt + delta_tilt,
             &lastRefPan, &lastRefTilt, panDeltaLimit, tiltDeltaLimit );
}

void BallTrackingHead::MoveHead(double s_pan, double s_tilt, double e_pan, double e_tilt,
                        double *r_pan, double *r_tilt, double pan_limit, double tilt_limit)
{
    RCRegion* rgn = FindFreeRegion();

    if (e_pan > s_pan + pan_limit) { e_pan = s_pan + pan_limit; }
    else if (e_pan < s_pan - pan_limit) { e_pan = s_pan - pan_limit; }
    *r_pan = e_pan;
    if (e_tilt > s_tilt + tilt_limit) { e_tilt = s_tilt + tilt_limit; }
    else if (e_tilt < s_tilt - tilt_limit) { e_tilt = s_tilt - tilt_limit; }
    *r_tilt = e_tilt;

    SetJointValue(rgn, PAN_INDEX, s_pan, e_pan);
    SetJointValue(rgn, TILT_INDEX, s_tilt, e_tilt);
    subject[sbjJoint]->SetData(rgn);
    subject[sbjJoint]->NotifyObservers();
}

void BallTrackingHead::SetJointValue(RCRegion* rgn, int idx, double start, double end)
{
    OCommandVectorData* cmdVecData = (OCommandVectorData*)rgn->Base();
    OCommandInfo* info = cmdVecData->GetInfo(idx);
    info->Set(odataJOINT_COMMAND2, jointID[idx], NUM_FRAMES);
    OCommandData* data = cmdVecData->GetData(idx);
    OJointCommandValue2* jval = (OJointCommandValue2*)data->value;

    double delta = end - start;
    for (int i = 0; i < NUM_FRAMES; i++) {
        double dval = start + (delta * i) / (double)NUM_FRAMES;
        jval[i].value = oradians(dval);
    }
}

RCRegion* BallTrackingHead::FindFreeRegion()
{
    for (int i = 0; i < NUM_COMMAND_VECTOR; i++) {
        if (region[i]->NumberOfReference() == 1) return region[i];
    }
    return 0;
}
```

BallTrackingHead_Sensor.cc

```
#include <OPENR/OSyslog.h>
#include "BallTrackingHead.h"

void BallTrackingHead::NotifySensor(const ONotifyEvent& event)
{
    RCRegion* rgn = event.RCData(0);

    if (initSensorIndex == false) {
        OSensorFrameVectorData* sv = (OSensorFrameVectorData*)rgn->Base();
        InitSensorIndex(sv);
        initSensorIndex = true;
    }
    if (sensorRegions.size() == NUM_SENSOR_VECTOR) {
        sensorRegions.front()->RemoveReference();
        sensorRegions.pop_front();
    }
    rgn->AddReference();
    sensorRegions.push_back(rgn);
    observer[event.ObsIndex()]->AssertReady();
}

void BallTrackingHead::InitSensorIndex(OSensorFrameVectorData* sensorVec)
{
    // jointID[] is already initialized in BallTrackingHead::OpenPrimitives().
    for (int i = 0; i < NUM_JOINTS; i++) {
        for (int j = 0; j < sensorVec->vectorInfo.numData; j++) {
            OSensorFrameInfo* info = sensorVec->GetInfo(j);
            if (info->primitiveID == jointID[i]) {
                sensoridx[i] = j;
                OSYSDEBUG(("[%2d] %s\n", sensoridx[i], JOINT_LOCATOR[i]));
                break;
            }
        }
    }
}

void BallTrackingHead::GetPanTiltAngle(longword frameNum, double* pan, double* tilt)
{
    list<RCRegion*>::iterator iter = sensorRegions.begin();
    list<RCRegion*>::iterator last = sensorRegions.end();
    OSensorFrameVectorData* sv;
    OSensorFrameInfo* info;
    OSensorFrameData* data;

    while (iter != last) {
        sv = (OSensorFrameVectorData*)(*iter)->Base();
        info = sv->GetInfo(sensoridx[PAN_INDEX]);
        longword fn = info->frameNumber;
        for (int i = 0; i < info->numFrames; i++) {
            if (fn == frameNum) {
                data = sv->GetData(sensoridx[PAN_INDEX]);
                *pan = degrees((double)data->frame[i].value / 1000000.0);
                data = sv->GetData(sensoridx[TILT_INDEX]);
                *tilt = degrees((double)data->frame[i].value / 1000000.0);
                return;
            }
            fn++;
            if (fn > oframeMAX_NUMBER) fn = 1;
        }
        ++iter;
    }

    // If sensor data at frameNum is not found, return latest sensor data.
    RCRegion* rgn = sensorRegions.back();
    sv = (OSensorFrameVectorData*)rgn->Base();
    info = sv->GetInfo(sensoridx[PAN_INDEX]);
    data = sv->GetData(sensoridx[PAN_INDEX]);
    *pan = degrees((double)data->frame[info->numFrames-1].value / 1000000.0);
    data = sv->GetData(sensoridx[TILT_INDEX]);
    *tilt = degrees((double)data->frame[info->numFrames-1].value / 1000000.0);
}
```