Simple Foraging and Random Aggregation Strategy for swarm robotics without communication

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***Abstract*— In swarm robotics Foraging and Aggregation are basic tasks yet that can be challenging when there is no communication between the robots. This paper proposes a strategy using a Mealy Deterministic Finite State Machine (DFSM) that switches between five states with two different algorithms, the Rebound avoider/follower through proximity sensors, and the Search blob/ePuck using the 2D image processing of the ePuck embedded camera. Ten trials for each scenario are simulated on V-rep in order to analyse the performance of the strategy in terms of the mean and standard deviation.**

I. FORAGING AND RANDOM AGGREGATION

The DFSM diagram in Fig. 1, which is defined by (1), starts in the Behaviour state where the robot is set as *avoider* while the time simulation is $t \leq 60[s]$. During that time, the Foraging state looks for the green blobs with the Search blob/ePuck algorithm while avoiding obstacles using the Rebound algorithm. Moreover, a Random Movement state is used to introduce randomness to the system so the agent can take different paths if there is no blob or obstacle detection. For $60 < t \leq 120$, the Behaviour of the robot is set to *follower* and switches to Random Aggregation state where it uses both algorithms, the Rebound to follow ePucks with the proximity sensors and the Search to look for the closest ePuck wheels. For both algorithms, the output is the angle of attack α_n, where n depends on the current state.

$$\begin{aligned} S &= \{B, F, R, A, Ra\} \\ \mathit{\Sigma} &= \{t \leq 60, 60 < t \leq 120, bl\ \exists, bl\ \nexists, ob\ \exists, ob\ \nexists, \\ &\qquad\qquad eP\ \exists, eP\ \nexists\} \\ s_0 &= \{B\} \end{aligned} \tag{1}$$

where, S is the finite set of states, $\mathit{\Sigma}$ is the input alphabet, $\delta : S \times \mathit{\Sigma}$ is the state transition function, s_0 is the initial state, $\exists$ and $\nexists$ mean detection and no detection respectively.

TABLE I: State transition function δ

Input	Current State	Next State	Output
$t \leq 60$	**B**ehaviour	**F**oraging	avoider
$60 < t \leq 120$	**B**ehaviour	**A**ggregation	follower
blob $\exists$	**F**oraging	**F**oraging	α_C
blob $\nexists$	**F**oraging	**Ra**ndom Mov.	α_{C_r}
obstacle $\exists$	**F**oraging	**R**ebound	α_R
obstacle $\nexists$	**R**ebound	**F**oraging	-
obstacle $\exists$	**A**ggregation	**R**ebound	α_R
obstacle $\nexists$	**R**ebound	**A**ggregation	-
ePuck $\exists$	**A**ggregation	**A**ggregation	α_e
ePuck $\nexists$	**A**ggregation	**Ra**ndom Mov.	α_{e_r}

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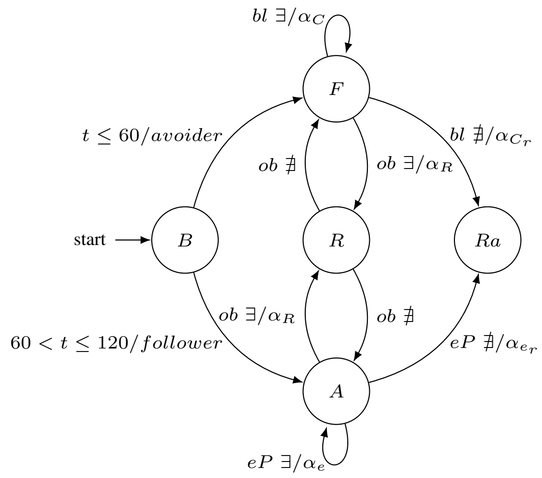


Fig. 1: Mealy DFSM of the controller

II. IMPLEMENTATION

A. Unicycle model

The Unicycle model in Fig. 2a [1] controls the angular velocities of the right and left wheels, v_r and v_l as follows,

$$\begin{aligned} v_r &= (2\ V_x + \omega\ L)/(2\ R) \\ v_l &= (2\ V_x - \omega\ L)/(2\ R) \end{aligned} \tag{2}$$

where, V_x is the linear velocity of the robot, L is the distance between the wheels, R is the radius of each wheel, and ω is the angular velocity of the robot. Using α_n and the simulation sampling period T, the control variable for the simulation is $\omega = \alpha_n/T$, refer to code line 24, 197 and 215.

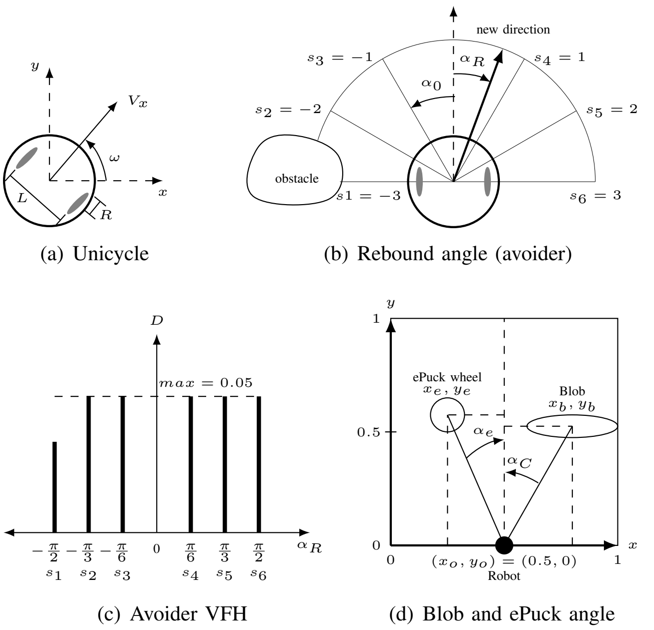
B. Rebound avoider/follower algorithm

The Rebound algorithm [2] calculates the Rebound angle α_R to avoid/follow an obstacle/objective given $\alpha_0 = \pi/N$ and $\alpha_i = i\ \alpha_0$,

$$\alpha_R = \frac{\sum_{i=-N/2}^{N/2}\ \alpha_i\ D_i}{\sum_{i=-N/2}^{N/2}\ D_i} \tag{3}$$

where, α_0 is the uniformly distributed angular pace, N is the number of sensors, α_i is the angular information per pace $\alpha_i\ \epsilon \left[-\frac{N}{2}, \frac{N}{2}\right]$, and D_i is the distance value obtained by the proximity sensors, refer to code line 18 and 139.

The weight vector given by α_i sets the robot behaviour for each corresponding mapped sensor $\{s_1, s_2, s_3, s_4, s_5, s_6\}$. For the *avoider* is $\{-3, -2, -1, 1, 2, 3\}$, and for the *follower* is $\{3, 2, 1, -1, -2, -3\}$. Fig. 2b and Fig. 2c show an example of α_R with the Vector Field Histogram (VFH) for the *avoider* case. Refer to code line 128 and 132.



(a) Unicycle (b) Rebound angle (avoider)

(c) Avoider VFH (d) Blob and ePuck angle

Fig. 2: Unicycle model, Rebound and Search angle

C. Search blob/ePuck algorithm

The ePuck embedded camera on V-rep is a vision sensor that filters the RGB colours of the blobs and other ePucks. Not collected Blobs are mapped as green and collected ones as red, and the ePuck wheels are also mapped because they have green and red parts, refer to code line 97. The data of interest that this sensor outputs are the size, centroid's 2D position, and orientation of the detected objects. Therefore, when objects are detected by the camera, a simple routine finds the biggest one which is the closest relative to the ePuck, and using (4) it can be calculated the angle of attack α_C or α_e for the blobs and ePucks respectively, refer to Fig. 2d and code line 150. The orientation value is used to differentiate between objects, for blobs is $= 0$ and for ePuck wheels is $\neq 0$, refer to code line 105.

$$\begin{aligned} \alpha_C &= \arctan\left[(x_b - x_o)/(y_b - y_o)\right] \\ \alpha_e &= \arctan\left[(x_e - x_o)/(y_e - y_o)\right] \end{aligned} \tag{4}$$

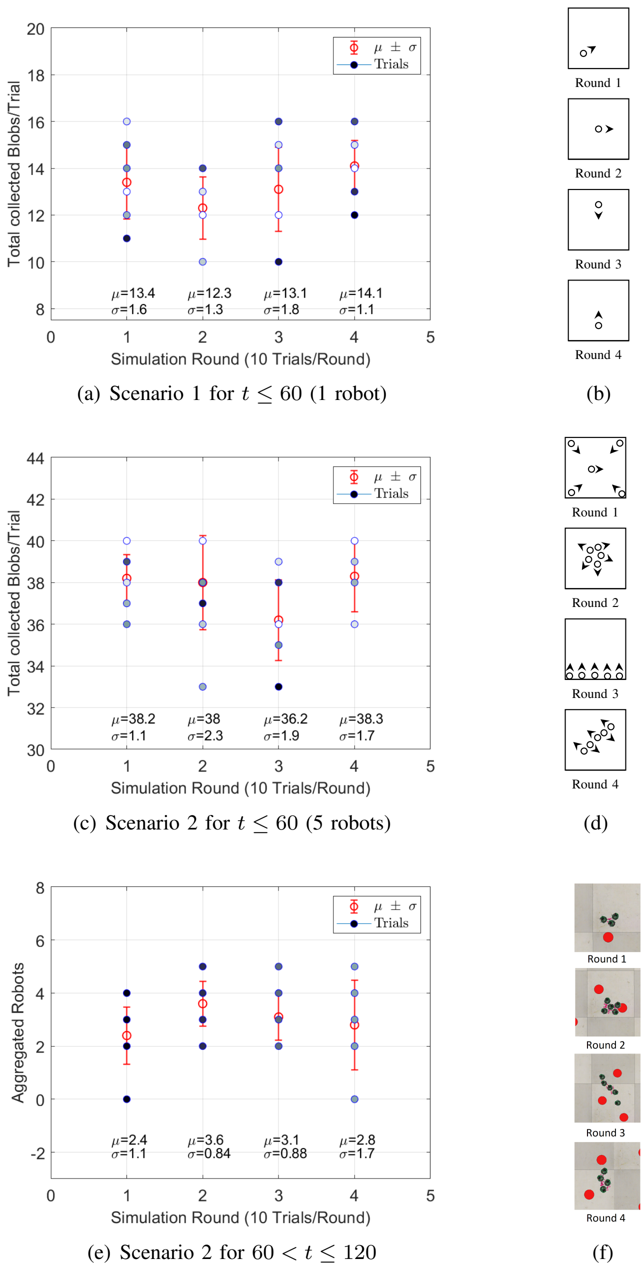
where, (x_o, y_o), (x_b, y_b), and (x_e, y_e) are the robot, blob and another ePuck wheel relative position in the 2D image. In the Random state, either the robot is foraging but does not see any blobs or is aggregating but there is no other ePuck nearby, (4) is modified with a random value w with a probability function P,

$$\begin{aligned} \alpha_{C_r} &= \alpha_C \ w \\ \alpha_{e_r} &= \alpha_e \ w \end{aligned} \tag{5}$$

where, $P(\{w \ \epsilon \ \Omega : X(w) = 1/3\})$ and $\Omega = \{-1, 0, 1\}$, refer to code line 158 and 205.

III. RESULTS AND DISCUSSION

For both Scenarios, 4 Rounds of 10 trials each are simulated. Each Round has different initial positions of the robots, Fig. 3b and Fig. 3d, and each trial stops at $t = 60$. In Scenario 1, Fig. 3a shows that Round 4 has the best performance because 68% of the time the robot will forage between 13 and 15 blobs. For Scenario 2, Fig. 3b shows that Round 1 hast the best performance, 68% of the time the swarm will forage between 37 and 39 blobs. For the Aggregation case that is simulated only in Scenario 2 Fig. 3e and Fig. 3f, Round 2 shows the best results, 68% of the time between 2 and 4 agents aggregate at some random point.



(a) Scenario 1 for $t \leq 60$ (1 robot) (b)

(c) Scenario 2 for $t \leq 60$ (5 robots) (d)

(e) Scenario 2 for $60 < t \leq 120$ (f)

Fig. 3: Simulation results

References

[1] Jawhar Ghommam, Maarouf Saad, and Faical Mnif. "Formation path following control of unicycle-type mobile robots". In: *2008 IEEE International Conference on Robotics and Automation*. IEEE, 2008. DOI: 10.1109/robot.2008.4543495.

[2] I. Susnea et al. "The bubble rebound obstacle avoidance algorithm for mobile robots". In: *IEEE ICCA 2010*. IEEE, 2010. DOI: 10.1109/icca.2010.5524302.

IV. Appendix

```
-- The University of Sheffield
-- ACS6121 Robotics and Autonomous Systems Spring 2018/19
-- V-rep Simulation Assignment
-- R. No. : 180123717
-- Name: Paulo Roberto Loma Marconi
---------------------------------------------------------------------------------------------
sim.setThreadAutomaticSwitch(false) -- manually switch the thread so we can control the sample period

-- init randomseed
math.randomseed(os.time())
math.random(); math.random(); math.random()

-- global constants
T=200 -- sample period [ms]
pi=math.pi


-- Bubble Rebound algorithm constants
N=6; alpha0=pi/N;

alphaR=0 -- [rad]
omega=0 -- [rad/s]

-- e-puck constants
-- http://www.e-puck.org/index.phpŒoption=com_content&view=article&id=7&Itemid=9
-- http://www.gctronic.com/e-puck_spec.php
maxWheelVel=6.24 -- Max angular wheel speed 6.24[rad/s]
maxVx=0.127 -- Max robot linear velocity, 0.127[m/s]=12.7[cm/s]
L=0.051 -- 5.1 cm, distance between the wheels
D=0.041 -- 4.1 cm, wheel diameter
R=D/2 -- wheel radius

timeSimul=60 -- time simulation threshold [s]

-- Functions: ---------------------------------------------------------------------------------
-- Color Blob detection
function colorDetect(idx,blobPosX,blobPosY)
    local blobCol=sim.getVisionSensorImage(ePuckCam,resu[1]*blobPosX[idx],resu[2]*blobPosY[idx],1,1)
    if (blobCol[1]>blobCol[2])and(blobCol[1]>blobCol[3]) then color='R' end
    if (blobCol[2]>blobCol[1])and(blobCol[2]>blobCol[3]) then color='G' end
    if (blobCol[3]>blobCol[1])and(blobCol[3]>blobCol[2]) then color='B' end
    return color
end

-- Biggest Blob
function bigBlob(blobSize)
    local maxVal,idx=-math.huge
    for k,v in pairs(blobSize) do
        if v>maxVal then
            maxVal,idx=v,k
        end
    end
    return idx
end

---------------------------------------------------------------------------------------------
-- This is the Epuck principal control script. It is threaded
threadFunction=function()
    while sim.getSimulationState()~=sim.simulation_advancing_abouttostop do
    t=sim.getSimulationTime()

-- Image Processing Part ======================================================================
    sim.handleVisionSensor(ePuckCam) -- the image processing camera is handled explicitely, since we do not need to execute that command at each simulation pass
    result,t0,t1=sim.readVisionSensor(ePuckCam) -- Here we read the image processing camera!
```

```
    resu=sim.getVisionSensorResolution(ePuckCam) -- Color blob detection init

-- The e-puck robot has Blob Detection filter. The code provided below get useful information
-- regarding blobs detected, such as amount, size, position, etc.

    -- t1[1]=blob count, t1[2]=dataSizePerBlob=value count per blob=vCnt,
    -- t1[3]=blob1 size, t1[4]=blob1 orientation,
    -- t1[5]=blob1 position x, t[6]=blob1 position y,
    -- t[7]=blob1 width, t[8]=blob1 height, ..., (3+vCnt+0) blob2 size,
    -- (3+vCnt+1) blob2 orientation, etc.

    pO={0.5,0} --[x0,y0] Relative Robot position in the 2D image
    blobSize={0}; blobOrientation={0};
    blobPos={0}; blobPosX={0}; blobPosY={0}
    blobBoxDimensions={0};
    blobColor={0};
    blobRedSize={0}; blobRedPosX={0}; blobRedPosY={0};
    blobGreenSize={0}; blobGreenPosX={0}; blobGreenPosY={0};
    ePuckOrientation={0}; ePuckSize={0}; ePuckPos={0}; ePuckPosX={0}; ePuckPosY={0};

    if (t1) then -- (if Detection is successful) in t1 we should have the blob information if the camera was set-up correctly
        blobCount=t1[1]
        dataSizePerBlob=t1[2]
        lowestYofDetection=100
        -- Now we go through all blobs:
        for i=1,blobCount,1 do
            blobSize[i]=t1[2+(i-1)*dataSizePerBlob+1]
            blobOrientation[i]=t1[2+(i-1)*dataSizePerBlob+2]
            blobPos[i]={t1[2+(i-1)*dataSizePerBlob+3],t1[2+(i-1)*dataSizePerBlob+4]} --[pos x,pos y]
            blobPosX[i]=t1[2+(i-1)*dataSizePerBlob+3]
            blobPosY[i]=t1[2+(i-1)*dataSizePerBlob+4]
            blobBoxDimensions[i]={t1[2+(i-1)*dataSizePerBlob+5],t1[2+(i-1)*dataSizePerBlob+6]} -- [w,h]
            -- Color detection of all blobs and group them by two vectors (Green and Red)
            blobColor[i]=colorDetect(i,blobPosX,blobPosY)
            if (blobColor[i]=='R') then
                blobRedSize[i]=blobSize[i]; blobRedPosX[i]=blobPosX[i]; blobRedPosY[i]=blobPosY[i];
            end
            if (blobColor[i]=='G') then
                blobGreenSize[i]=blobSize[i]; blobGreenPosX[i]=blobPosX[i]; blobGreenPosY[i]=blobPosY[i];
            end
            -- Detect the orientation, size and position of the detected ePucks
            if (blobOrientation[i]~=-0) then
                ePuckOrientation[i]=blobOrientation[i];
                ePuckSize[i]=blobSize[i]; ePuckPos[i]=blobPos[i];
                ePuckPosX[i]=blobPosX[i]; ePuckPosY[i]=blobPosY[i];
                flagEPuck=1;
            end
        end
    end

-- Proximity sensor readings ==============================================================================
    s=sim.getObjectSizeFactor(bodyElements) -- make sure that if we scale the robot during simulation, other values are scaled too!
    noDetectionDistance=0.05*s
    proxSensDist={noDetectionDistance,noDetectionDistance,noDetectionDistance,noDetectionDistance, noDetectionDistance,noDetectionDistance,noDetectionDistance,noDetectionDistance}
    for i=1,8,1 do
        res,dist=sim.readProximitySensor(proxSens[i])
        if (res>0) and (dist<noDetectionDistance) then
            proxSensDist[i]=dist
        end
    end

-- Controller Algorithm ===================================================================================

    -- Behaviour state: ----------------------------------------------------------------------------
    if (t<=timeSimul) then behaviour='avoider'
    else behaviour='follower' end

    -- Define the weight vector
    if (behaviour=='avoider') then
        alpha={-3*alpha0,-2*alpha0,-1*alpha0,1*alpha0,2*alpha0,3*alpha0} -- avoider weight vector
    elseif (behaviour=='follower') then
        alpha={3*alpha0,2*alpha0,1*alpha0,-1*alpha0,-2*alpha0,-3*alpha0} -- follower weight vector
```

```
  end

 -- Rebound avoider/follower algorithm ---------------------------------------------------------------
  -- Calculate the angle of attack alphaR
  sum_alphaD=0; sumD=0;
  for j=1,N,1 do
    sum_alphaD=sum_alphaD+alpha[j]*proxSensDist[j]
  end
  for j=1,N,1 do
    sumD=sumD+proxSensDist[j]
  end
  alphaR=sum_alphaD/sumD

  -- Foraging State: -------------------------------------------------------------------------------
 -- Search blobb/ePuck algorithm
  -- Find the biggest green Blob index using the blobGreenSize vector data
  idx=bigBlob(blobGreenSize)

  -- Angle to the closest green Blob given by the biggest blob idx
  alphaC=math.atan((blobGreenPosX[idx]-pO[1])/(blobGreenPosY[idx]-pO[2]))

  -- Random State: Makes a random movement when there is no Blob detection
  if (math.deg(alphaC)==-90) or (math.deg(alphaC)==90) then
    alphaC=2*alphaC*math.random(-1,1)
  end

  -- Agregation State for 60<t<=120: -----------------------------------------------------------------
  -- Find the biggest ePuck wheel
 idxEPuck=bigBlob(ePuckSize)
 -- Angle to the biggest ePuck wheel
  alphaEPuck=math.atan((ePuckPosX[idxEPuck]-pO[1])/(ePuckPosY[idxEPuck]-pO[2]))

-- Ouput ==========================================================================================

  -- Vx for avoider/follower -------------------------------------------------------------------------
  threshold=0.015 -- threshold detection
  Vx=maxVx -- go straight

  if (behaviour=='avoider') then
    if (proxSensDist[2]<threshold) or (proxSensDist[3]<threshold) or (proxSensDist[4]<threshold) or (proxSensDist[5]<threshold)  then
      Vx=0; -- stop robot
      -- Corrected angle due the symmetrical obstacle in front of the robot, only applicable in the avoider
      if alphaR==0 then alphaR=pi*math.random(-1,1) end
    end
  end

  if (behaviour=='follower') then
    Vx=maxVx
    if (proxSensDist[2]<threshold) or (proxSensDist[3]<threshold) or (proxSensDist[4]<threshold) or (proxSensDist[5]<threshold) then
      Vx=0; -- stop robot
    end
  end

  -- Obstacle Detection/noDetection flag ----------------------------------------------------------------
  if (proxSensDist[1]==0.05)and(proxSensDist[2]==0.05)and(proxSensDist[3]==0.05)and(proxSensDist[4]==0.05)and(proxSensDist[5]==0.05)and(proxSensDist[6]==0.05) then
    flag='noObsDetection'
  else
    flag='ObsDetection'
  end

  -- Output omega [rad/s]=instantaneous robot angular velocity. T[ms]/1000[ms]=t[s] -------------------
  if (t<=timeSimul) then -- avoider+ObsDetection/noObsDetection+alphaR+alphaC
    if (flag=='ObsDetection') then
      omega=alphaR/(T/1000); flg='Rebound';
    elseif (flag=='noObsDetection') then
      omega=alphaC/(T/1000); flg='Camera';
    end
  else                  -- follower +alphaEPuck
    -- Random state: Random movement when there is no ePuck detection
    if (math.deg(alphaEPuck)==-90) or (math.deg(alphaEPuck)==90) then
      alphaEPuck=2*alphaEPuck*math.random(-1,1)
```

```
        end
        if (flagEPuck~=1) then
            alphaEPuck=0;
        end
        omega=alphaEPuck/(T/1000); flg='ePuck';
    end

    -- Angular velocities of the wheels using the Unicycle model, vr and vl  ----------------------------
    velLeft=(2*Vx+omega*L)/(2*R); -- rad/s
    velRight=(2*Vx-omega*L)/(2*R); -- rad/s

    -- Wheel velocity constraints ------------------------------------------------------------------------
    if (velLeft>maxWheelVel) then velLeft=maxWheelVel
    elseif (velLeft<-maxWheelVel) then velLeft=-maxWheelVel end
    if (velRight>maxWheelVel) then velRight=maxWheelVel
    elseif (velRight<-maxWheelVel) then velRight=-maxWheelVel end

    -- Right/Left motor output  --------------------------------------------------------------------------
    sim.setJointTargetVelocity(leftMotor,velLeft)
    sim.setJointTargetVelocity(rightMotor,velRight)

  print('time',t,'behaviour',behaviour,'flg',flg,'Vx',Vx,'omega',omega,'velLeft',velLeft,'velRight',
    velRight)

    sim.switchThread() -- Don't waste too much time in here (simulation time will anyway only change in
    next thread switch)
                       -- we switch the thread now!


    end -- end while
end --  end thread function

------------------------------------------------------------------------------------------------------
-- These are handles, you do not need to change here. (If you need e.g. bluetooth, you can add it here)

sim.setThreadSwitchTiming(T) -- We will manually switch in the main loop (200)
bodyElements=sim.getObjectHandle('ePuck_bodyElements')
leftMotor=sim.getObjectHandle('ePuck_leftJoint')
rightMotor=sim.getObjectHandle('ePuck_rightJoint')
ePuck=sim.getObjectHandle('ePuck')
ePuckCam=sim.getObjectHandle('ePuck_camera')
ePuckBase=sim.getObjectHandle('ePuck_base')
ledLight=sim.getObjectHandle('ePuck_ledLight')

proxSens={-1,-1,-1,-1,-1,-1,-1,-1}
for i=1,8,1 do
    proxSens[i]=sim.getObjectHandle('ePuck_proxSensor'..i)
end


res,err=xpcall(threadFunction,function(err) return debug.traceback(err) end)
if not res then
    sim.addStatusbarMessage('Lua runtime error: '..err)
end
```