Using LEGO® Mindstorms and MATLAB in Curriculum Design of Active Learning Activities for a First-year Engineering Computing Course

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Background: ENCP 100

• Engineering, Computer 100 (ENCP 100)
  – Mandatory to all first-year engineering students

• 13-week introductory programming course in MATLAB, with problem-solving methodology

• Teaches students the fundamentals of computer programming [1]
Background: MATLAB

• “A programming platform designed specifically for engineers and scientists... a matrix-based language allowing the most natural expression of computational mathematics.” [2]

• Analyze, format, graph, and manipulate data
• Develop algorithms
• Create models and applications
Research Project Goals

1. Investigate literature to explore the use of active learning tools in first-year engineering education
2. Determine the capabilities of the LEGO® Mindstorms platform as an “active learning” tool
3. Use the information gained to propose and test active learning lab activities
Inspiration for this research project came from two papers by Behrens et al [3], [4].

Freshman engineering introduction course at RWTH Aachen University, Germany

309 students given 100 LEGO Mindstorms robots

“Encouraged [students] to transfer known mathematical basics to program algorithms and real-world applications”
Literature Review : Behrens et al.

• Conclusion:
  ➢ “Successfully boosts students’ motivation, advances their programming skills, and encourages the peer learning process”
Literature Review

• Traditional teaching methodologies focussed on knowledge transfer are becoming obsolete; “knowledge acquisition must be linked to their application” [5]

• “This study has found support for all forms of active learning examined... benefits of student engagement...likely to positively influence student attitudes and study habits... students will retain information longer and develop enhanced critical thinking and problem-solving skills” [6]
Literature Review

• Reviewed over 100 research papers
• 89 applicable research papers

• The problem: very few specifics on the activities and assignments
• Nearly all was qualitative research
LEGO® Mindstorms

- A programmable robotics construction set
- ~$400 CAD per set
- 2 large motors
- 1 medium motor
- 5 sensors

Fred Version 1.5

Beacon Remote

- Ultrasonic Sensor
- Infrared Sensor
- Medium Motor
- Color Sensor
- Gyroscope Sensor
Mindstorms and MATLAB

• Connect the EV3 Intelligent Brick to a computer via USB, wi-fi, or Bluetooth connection

• Free MATLAB add-on, “MATLAB Support Package for LEGO MINDSTORMS EV3 Hardware” is needed
Barney

Ev3meg Design

Claw Version 1

Claw Version 2
Coding Mindstorms: Simple Tasks

Moving Forward

Fred = legoev3('usb')
myLeg1 = motor(Fred, 'B')
myLeg2 = motor(Fred, 'C')

myLeg1.Speed = 50
myLeg2.Speed = 50

start(myLeg1)
start(myLeg2)

pause(3)

stop(myLeg1)
stop(myLeg2)

Motion Alarm

Fred = legoev3('usb')

mysensor = sonicSensor(Fred)

while ~readButton(Fred, 'up')
    d = readDistance(mysensor);
    if d < 1
        freq = 500*(1-d)
        volume = 100*(1-d)
        playTone(Fred, freq, 1, volume)
    end
end
### Coding Mindstorms: Sounds

<table>
<thead>
<tr>
<th>Frequencies</th>
<th>Tone</th>
</tr>
</thead>
<tbody>
<tr>
<td>c = 261;</td>
<td>playTone(Fred,c,.5,5) pause(.5)</td>
</tr>
<tr>
<td>d = 294;</td>
<td>playTone(Fred,d,.5,5) pause(.5)</td>
</tr>
<tr>
<td>e = 339;</td>
<td>playTone(Fred,e,.5,5) pause(.5)</td>
</tr>
<tr>
<td>f = 349;</td>
<td>playTone(Fred,f,.5,5) pause(.5)</td>
</tr>
<tr>
<td>g = 391;</td>
<td>playTone(Fred,g,.5,5) pause(.5)</td>
</tr>
<tr>
<td>g3 = 415;</td>
<td>playTone(Fred,g3,.5,5) pause(.35)</td>
</tr>
<tr>
<td>a = 440;</td>
<td>playTone(Fred,a,.5,5) pause(.15)</td>
</tr>
<tr>
<td>a3 = 455;</td>
<td>playTone(Fred,a3,.5,5) pause(.5)</td>
</tr>
<tr>
<td>b = 466;</td>
<td>playTone(Fred,b,.35,5) pause(.35)</td>
</tr>
<tr>
<td>cH = 523;</td>
<td>playTone(Fred,cH,.15,5) pause(.15)</td>
</tr>
<tr>
<td>c#H = 554;</td>
<td>playTone(Fred,c#H,.5,5) pause(.35)</td>
</tr>
<tr>
<td>dH = 587;</td>
<td>playTone(Fred,dH,.5,5) pause(.35)</td>
</tr>
<tr>
<td>d#H = 622;</td>
<td>playTone(Fred,d#H,.15,5) pause(.15)</td>
</tr>
<tr>
<td>eH = 659;</td>
<td>playTone(Fred,eH,.65,5) pause(.15)</td>
</tr>
<tr>
<td>fH = 696;</td>
<td>playTone(Fred,fH,.65,5) pause(.15)</td>
</tr>
<tr>
<td>f#H = 740;</td>
<td>playTone(Fred,f#H,.65,5) pause(.65)</td>
</tr>
<tr>
<td>gH = 784;</td>
<td>playTone(Fred,gH,.65,5) pause(.65)</td>
</tr>
<tr>
<td>g#H = 830;</td>
<td>playTone(Fred,g#H,.65,5) pause(.65)</td>
</tr>
<tr>
<td>aH = 880;</td>
<td>playTone(Fred,aH,.65,5) pause(.65)</td>
</tr>
</tbody>
</table>
Coding Mindstorms: Display
Fred = lego3('pb');
scan = motor(Fred,'s');
myLeg1 = motor(Fred,'1');
myLeg2 = motor(Fred,'2');
myColor = colorSensor(Fred,4);
gather = true;
j = 0;
while gather
    j = j + 1;
    i = 0;
    forward = true;
    scan_speed = -10;
    start(scan);
tic
    while forward
        time = toc;
        if time >= 0.6
            scan_speed = 0;
            start(scan);
            forward = false;
        end
        i = i + 1;
        scan_value(i,:) =
        pause(0.3);
    end
    if j == 20
        gather = false;
    end
end
while back
    scan_speed = 10;
    start(scan);
    time = toc;
    if time >= 0.7
        scan_speed = 0;
        start(scan);
        back = false;
    end
end
for j = 1:nxc
    for i = 1:length(color,2)*5
        if scan_value(j,i) < 50
            x(j,i) = i;
        else
            x(j,i) = nan;
        end
    end
    for i = 6:length(color,2)*5
        if scan_value(j,i) < 50
            x(j,i) = i;
        else
            x(j,i) = nan;
        end
    end
end
y = nan(length(x,2))*10;
plot(x, y, 'r','markers',17,'MarkerFaceColor',[0 0 0])
axis([0, length(x), 0, y])
sticks(0,2:length(x))
grid on
## Analyzing 2018 Lab Assignments

<table>
<thead>
<tr>
<th>Asgn. #</th>
<th>Main Topic</th>
<th>Subtopics</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Course outline and introduction</td>
<td>Introduction to computers and MATLAB environment</td>
</tr>
<tr>
<td>2</td>
<td>Problem solving and expression assignment</td>
<td>Pseudo-code, flow charts, program structure, variable assignment, math operators, precedence, built-in functions</td>
</tr>
<tr>
<td>3</td>
<td>Arrays and plotting</td>
<td>Array initialization, indexing, operations, plotting</td>
</tr>
<tr>
<td>4</td>
<td>Logical data types and selection flow control</td>
<td>Logical data types, ifelse, select</td>
</tr>
<tr>
<td>5</td>
<td>Repetition flow control</td>
<td>Control mechanisms: for, while, convergence</td>
</tr>
<tr>
<td>6</td>
<td>Functions</td>
<td>M-file, anonymous, and recursive functions</td>
</tr>
<tr>
<td>7</td>
<td>Numeric data types</td>
<td>Integers, floating point, precision vs. round-off error</td>
</tr>
<tr>
<td>8</td>
<td>Data types: Character and heterogeneous</td>
<td>Characters, structures, cell arrays</td>
</tr>
<tr>
<td>9</td>
<td>Input / Output</td>
<td>Standard and file I/O</td>
</tr>
<tr>
<td>10</td>
<td>Validation and verification</td>
<td>Testing and debugging, variable checking</td>
</tr>
<tr>
<td>11</td>
<td>Engineering problems</td>
<td>Various possible topics</td>
</tr>
<tr>
<td>12</td>
<td>Review</td>
<td></td>
</tr>
</tbody>
</table>
Creating New Assignments

- Review tasks from previous 2018 assignments
- Achieve the same learning objectives while incorporating LEGO Mindstorms
- Test and develop code for all proposed tasks to validate the proposed assignments
## Proposed Lab Assignments

<table>
<thead>
<tr>
<th>Asgn. #</th>
<th>Goal</th>
<th>Assignment Task</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Introduction to MATLAB</td>
<td>Interfacing robot with MATLAB – output to screen</td>
</tr>
<tr>
<td>2</td>
<td>Exploring MATLAB features</td>
<td>Interfacing robot with MATLAB – exploring use of motors and sensors (syntax, built-in functions, operators, and data types)</td>
</tr>
<tr>
<td>3</td>
<td>Solution procedure – simple programs</td>
<td>Creating simple programs using robot’s motors and sensors, and creating flow charts and pseudo code</td>
</tr>
<tr>
<td>4</td>
<td>Using arrays and plotting</td>
<td>Gather data using a sensor, plot data</td>
</tr>
<tr>
<td>5</td>
<td>Logic – decisions, conditional statements</td>
<td>Object detection and avoidance Braintenberg Vehicles – complex behaviors using simple sensors</td>
</tr>
<tr>
<td>6</td>
<td>Repetition</td>
<td>Automatic Motion with Object avoidance (Random Walk)</td>
</tr>
<tr>
<td>7</td>
<td>Functions</td>
<td>Dead Reckoning or other applications using functionality of robot</td>
</tr>
<tr>
<td>8</td>
<td>Numeric Data types</td>
<td>I2C communication – understanding digital data transfer</td>
</tr>
<tr>
<td>9</td>
<td>Character</td>
<td>Send string instructions to robot to execute various tasks</td>
</tr>
<tr>
<td>10</td>
<td>Standard and File I/O</td>
<td>Collect data and periodically sync with computer to download</td>
</tr>
<tr>
<td>11</td>
<td>Engineering Application</td>
<td>Building advanced robot functionality through structures</td>
</tr>
<tr>
<td>12</td>
<td>Advanced</td>
<td>Students develop complex programming project to encompass all learning outcomes – i.e. maze solving algorithms, color tracking</td>
</tr>
</tbody>
</table>
Missing Elements

• Assignment 2 fails to incorporate the robot for: rewriting expressions in MATLAB, use regular built-in MATLAB functions, learn syntax

• Assignment 8 fails to incorporate the robot for: general base conversions – previously given as a hand-written task
Difficulties

• Battery-powered, bad battery life (3-4 days)
• Couldn’t connect to school wi-fi due to log-in screens
Conclusion

• The functionalities of the sensors and motors offer many opportunities to demonstrate programming concepts and create different assignments from year to year

• The LEGO® Mindstorms EV3 robot combined with MATLAB programming language would be feasible for implementing in a first-year programming course

• The proposed activities satisfy the learning outcomes and show potential for improving student outcomes
Thank you

Questions?
References


