DARE: DESCENDING/ ASCENDING ROVER FOR EXPLORATION

Preliminary Design Review
October 24, 2013

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Developed:
• 1st generation Mother Rover (MR)
• Optical navigation system

Purchased:
• 2 COTS Child Rover (CR)

**Remus**

Developed:
• 1st generation CR
• 2nd generation MR
• 2D ultrasonic “cricket” navigation system
• CR imaging system

**Xrover**

Developed:
• 3rd generation MR
• Deployable MR ramp
• Enhanced relay COM system
• 2nd generation CR
• CR rocker-bogie suspension

**Starr**

Developed:
• 3rd generation CR
• Sample identification based on color
• CR sample collection and retrieval

**Treads**

Developed:
• 4th generation MR
• Sample storage
• Multiple CR storage
• Retractable ramp
• Driving
• LEDs for deployment and retrieval of CRs

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**Summary**

2008 - 2009
- 1st generation MR
- COTS Child CR

2009 - 2010
- 2nd generation MR
- 1st generation CR

2010 - 2011
- 3rd generation MR
- 2nd generation CR

2011 - 2012
- 4th generation MR
- Sample storage
- Multiple CR storage

2012 - 2013
- Retractable ramp
- Driving
- LEDs for deployment and retrieval of CRs

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The goal of this project is to design and build a Child Rover (CR) that is capable of deploying, communicating, and docking with the previously designed TREADS Mother Rover (MR), while also being able to ascend and descend slopes between 30° and 70°. These slopes will replicate a sandstone surface found when exploring canyon walls, craters, and caverns.
OBJECTIVES

- The CR will deploy from and dock with the TREADS MR
- The CR will communicate with the MR and the Ground Station (GS)
- The CR will determine its position relative to the MR to within 1m and its elevation angle to within 5°
- The CR will capture color images
- The CR will travel up to 20m on level terrain
- After deploying from the MR and travelling a maximum of 20m across flat ground, the CR will ascend and/or descend a slope of 30° to 70°, then return to the MR
R.1) The CR shall deploy from and dock with the TREADS MR.
   R.1.1) The CR shall have an area no greater than 46cm x 92cm.
   R.1.2) The CR shall weigh no more than 7.26kg.
   R.1.3) The CR shall use the legacy docking navigation system.

R.2) The CR shall communicate.
   R.2.1) The CR shall communicate with the MR.
      R.2.1.1) The CR shall transmit images to the MR.
      R.2.1.2) The CR shall receive commands from the MR.
      R.2.1.3) The CR shall transmit telemetry data to the MR.
      R.2.1.4) The CR shall function within the maximum range of 40m from the MR.
      R.2.1.5) The CR shall be capable of transferring 10kbps.
   R.2.2) The CR shall communicate with the GS.
      R.2.2.1) The CR shall receive commands from the GS.

R.3) The CR shall perform navigation.
   R.3.1) The CR shall know its relative position to the MR to within ±1m.
   R.3.2) The CR shall know its elevation angle to within ±5°.
   R.3.3) The CR shall know the distance travelled before the ascent or descent.

R.4) The CR shall capture color images.
   R.4.1) The image shall have a resolution of at least 160 x 120 pixels.
   R.4.2) The camera shall be capable of panning a maximum angle of 60° in both directions.
   R.4.3) The camera shall be capable of tilting a maximum angle of 20° in both directions.
R.5) The CR shall travel up to 20m on level terrain.*
R.6) The CR shall be able to travel to a location of interest up to 20m from the MR before descending or ascending.
   R.6.1) The CR shall descend a slope for a maximum of 20m.
      R.6.1.1) The CR shall descend a slope of 30° then return to the MR.
      R.6.1.2) The CR shall descend a slope of 50° then return to the MR.
      R.6.1.3) The CR shall descend a slope of 70° then return to the MR.
   R.6.2) The CR shall ascend a slope for a maximum of 20m.
      R.7.1.1) The CR shall ascend a slope of 30° then return to the MR.
      R.7.1.2) The CR shall ascend a slope of 50° then return to the MR.
      R.7.1.3) The CR shall ascend a slope of 70° then return to the MR.
The MR is first deployed in an area to be explored. The MR is maneuvered to a desired location via commands from the ground station. The DARE project begins with the DARE CR being deployed from the MR bay.
The DARE CR will be capable of traversing level ground for a max of 20m after deployment. During this time it will be receiving commands from the MR and will be capable of reporting its position to the MR to within ±1m. At any point during this phase the CR will be capable of taking a photograph and transmitting it back to the MR.
There are 2 mission alternatives for step 3. In this mission, the CR will ascend a slope of 70° for a maximum of 20m. After reaching the apex of its climb, the CR will descend the 70° slope to return to the MR. During this time it will be receiving commands from the MR and will be capable of reporting its position to the MR to within ±1m and its elevation angle from the mother to within ±5°. At any point during this phase the CR will be capable of taking a photograph and transmitting it back to the MR.
In this mission, the CR will descend a slope of 70° for a maximum of 20m. After reaching the apex of its climb, the CR will descend the 70° slope to return to the MR. During this time it will be receiving commands from the MR and will be capable of reporting its position to the MR within ±1m and its elevation angle from the mother to within ±5°. At any point during this phase the CR will be capable of taking a photograph and transmitting it back to the MR.
The DARE CR will return to the MR. During this time it will be receiving commands from the MR, and will be capable of reporting its position to the MR within ±1m. At any point during this phase the CR will be capable of taking a photograph and transmitting it back to the MR.
The DARE CR will dock into one of the MR bays. This concludes the DARE project mission. After this point, the MR can move to a new location and deploy the DARE rover on a new mission.
FUNCTIONAL BLOCK DIAGRAM

Project Description

Critical Project Elements

Additional Elements

Summary

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Trade studies conducted:
- Surface interaction
- Navigation
- Locomotion

Additional investigations:
- Electronic Power System (EPS)
- Legacy rover status
Surface Interaction:
- High friction wheels
- Electric Ducted Fan (EDF)

Locomotion:
- Wheels
- Direct drive

Communication:
- 802.11g Wi-Fi

EPS:
- On-board power

Navigation:
- Encoder
- Inclinometer

Software:
- Build on legacy

Camera
- COTS
# EVIDENCE OF BASELINE FEASIBILITY

## Project Description

<table>
<thead>
<tr>
<th>Critical Project Elements</th>
<th>Additional Elements</th>
<th>Summary</th>
</tr>
</thead>
</table>

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CRITICAL PROJECT ELEMENTS

- **Surface Interaction:**
  - High friction wheels
  - Electric Ducted Fan (EDF)

- **Locomotion:**
  - Wheels
  - Direct drive

- **Communication:**
  - 802.11g Wi-Fi

- **EPS:**
  - On-board power

- **Navigation:**
  - Encoder
  - Inclinometer

- **Software:**
  - Build on legacy

- **Camera**
  - COTS

Critical Project Elements

![Diagram of a robot with high friction wheels and electric ducted fan]
Known Maximum Values\textsuperscript{3,4}

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass</td>
<td>7.25 kg</td>
</tr>
<tr>
<td>Dimension</td>
<td>46 x 92 cm</td>
</tr>
<tr>
<td>Acceleration</td>
<td>3.16 m/s(^2)</td>
</tr>
<tr>
<td>Distance</td>
<td>20 m level, 20 m inclined</td>
</tr>
<tr>
<td>Angle</td>
<td>70°</td>
</tr>
</tbody>
</table>

Experimentation
- Coefficient of friction

Research
- Max fan force possible
- On-board power available
- Radius of wheel

Unknown
- Mission duration
- Max Power required
- Energy required
Purpose
- Critical for ascending/descending slopes
  - Requirements: R.5, R.6

Design
- Deformable wheels
  - Increases surface area
- Sandpaper treads

Feasibility
- Coefficient of friction study
SURFACE INTERACTION: HIGH FRICTION WHEELS

Procedure:
- Raised surface until block moved and recorded corresponding angle
- Two surface types and two sand paper grits
- Used known equation to find coefficient of static friction, $\mu_s$
  \[ \mu_s = \tan(\theta) \]

Surface
- Thin sand
- Thick sand
# Experimental Results

<table>
<thead>
<tr>
<th>Trial</th>
<th>Thick Sand Layer</th>
<th>Thin Sand Layer</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>80 grit</td>
<td>100 grit</td>
</tr>
<tr>
<td>1</td>
<td>43.5</td>
<td>41.5</td>
</tr>
<tr>
<td>2</td>
<td>44</td>
<td>39.5</td>
</tr>
<tr>
<td>3</td>
<td>43.5</td>
<td>41</td>
</tr>
<tr>
<td>4</td>
<td>43</td>
<td>41.5</td>
</tr>
<tr>
<td>5</td>
<td>44</td>
<td>40</td>
</tr>
<tr>
<td>Average</td>
<td>43.6</td>
<td>40.7</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>0.01</td>
<td>0.02</td>
</tr>
<tr>
<td>Coefficient of Friction</td>
<td>0.95</td>
<td>0.86</td>
</tr>
</tbody>
</table>
SURFACE INTERACTION: EDF

- **Purpose**
  - Critical for ascending/descending slopes
    - Requirements: R.5, R.6

- **Design**
  - Use high velocity fan to pull air out from under CR
  - Increases the normal force of the CR
    - Increase in normal force increases friction force

- **Feasibility**
  - Free body diagram analysis
  - Research fan options
Assumptions:
- No slip condition
- Rigid body
- Center of mass is located at geometric center

Force Analysis:
- Gravitational Force
- $F_T$ - EDF Static Thrust
- $f$ - Friction Force
- $N$ - Normal Force
**SURFACE INTERACTION: EDF**

- **Maximum fan force necessary = 49N**
  - CR mass = 6.6kg
  - Maximum acceleration = 1 m/s²
  - Coefficient of friction = 0.95
  - Inclination angle = 70°

- **Feasible with TJ110 plug-n-play⁶**
  - Maximum thrust = 60 N
    - Provides design margin
  - Mass = .91 kg
  - Diameter = 11.5 cm
  - Power = 4.3 kW
Purpose
- Critical for ascending/descending slopes
  - Requirements: R.1, R.5, R.6

Design
- Four wheels with direct drive motors
  - Ability to turn
  - Reduce mass
- Brushless motors
  - High efficiency
- Suspension necessary
  - Maintain normal fan force over discontinuities
  - Torsion rod suspension is a possibility as shown in figure

Feasibility
- Direct drive used in legacy system
- Added deformable wheels with sandpaper tread
- Status check: successful motion
COMMUNICATION

Purpose
- Critical for communicating with MR and GS
  - Requirements: R.2^4

Design
- Utilize legacy system communication

Feasibility
- Communication design driver
  - Images
  - Range
- Preliminary range test
Legacy System

- Overo Fire Gumstix
- Image size (8-bit RGB)
  - For high resolution (1600x1200): 1875kb
  - For low resolution (160x120): 18.75kb
- 802.11g Wi-Fi
  - ~46m indoor range
  - ~92m outdoor range
COMMUNICATION TEST

- **Test:**
  - Speed and reliability of legacy Wi-Fi up to 40m

- **Location:**
  - AES Hallway (Outside Lockheed Martin Room)

- **Results:**
  - Inconsistent test results
  - Random lag between commands
  - CR failure @ ~10m, @ ~25m

- **Possible reasons:**
  - Interference in the hallway
  - Command pathways
  - Circuit issues

- **Additional testing needed**
Purpose
- Critical for implementation of all systems
  - Requirements: R.1, R.2, R.3, R.4, R.5, R.6

Design
- On-board power

Feasibility
- Power requirements of components
- Power design driver: EDF
- Battery research
Calculate mechanical power as Potential Energy (PE)
- Assume climbing 70° incline for 80m
- This assures power is more than max

Research power values for:
- Navigation
- Computer/Communications
- Camera
- Arduino
- EDF
## Power System Standard Components

<table>
<thead>
<tr>
<th>Component</th>
<th>Amps</th>
<th>Volts</th>
<th>Power (W)</th>
<th>Time on (s)</th>
<th>Energy (J)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motors*</td>
<td>5</td>
<td>9.4</td>
<td>44</td>
<td>4300</td>
<td>1032000</td>
</tr>
<tr>
<td>Computer/Communications(^{13})</td>
<td>0.25</td>
<td>5</td>
<td>1</td>
<td>1100</td>
<td>1100</td>
</tr>
<tr>
<td>Arduino(^{14})</td>
<td>2</td>
<td>5</td>
<td>10</td>
<td>1100</td>
<td>11000</td>
</tr>
<tr>
<td>Camera(^{16})</td>
<td>1.5</td>
<td>5</td>
<td>10</td>
<td>300</td>
<td>3000</td>
</tr>
<tr>
<td>Navigation(^{17,19})</td>
<td>0.07</td>
<td>5</td>
<td>0.35</td>
<td>1100</td>
<td>385</td>
</tr>
<tr>
<td><strong>Total:</strong></td>
<td></td>
<td></td>
<td><strong>8.82</strong></td>
<td></td>
<td><strong>20840</strong></td>
</tr>
</tbody>
</table>

## Power System Design Driver EDF

<table>
<thead>
<tr>
<th>Component</th>
<th>Amps</th>
<th>Volts</th>
<th>Power (W)</th>
<th>Time on (s)</th>
<th>Energy (J)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fan(^{6})</td>
<td>94</td>
<td>44</td>
<td>4300</td>
<td>300</td>
<td>1032000</td>
</tr>
</tbody>
</table>

* Estimate based on potential energy calculation from previous page

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### Project Description

Critical Project Elements

Additional Elements

Strategy
Batteries Available

- Zippy Flightmax6S1P\textsuperscript{18}
  - Capacity (C): 5000 mAh
  - Discharge rate (DR):
    - 30 C constant
    - 40 C burst
  - Mass: 784 g
  - Voltage: 22.2V
- *Safety concern*

- Link 2 in parallel to power fan\textsuperscript{6}
  - Pulling 94 amps~ 100 amps
    - Total climb and descend time (t) = 300s
    - Let climb and descend velocity (v) = .25m/s

- Use an additional battery for on-board electronics and motors

Maintains mass used in EDF analysis.

Maintains enough normal force to maintain necessary friction force.

Total movement time on incline = 160s
Total loiter time on incline = 140s
Total incline design margin = 60s
ADDITIONAL PROJECT ELEMENTS

- Project Description
- Critical Project Elements
- Additional Elements
- Summary
Purpose
- Critical to determine position relative to MR
  - Requirements: R.3

Design
- Encoder
- Inclinometer

Feasibility
- Encoder
  - Designing for no slip
  - Successfully used by TREADS legacy system for exploration
- Inclinometer
  - Accuracy ranges 0.01° to 0.5°
  - Only measure statically, to minimize drift
SOFTWARE

Purpose
- Critical for implementation and integration of all systems
  - Requirements: R.1, R.2, R.3, R.4, R.5, R.6

Design
- Build on legacy project

Feasibility
- Software architecture review
**Project Description**

**Critical Project Elements**

**Additional Elements**

**Summary**

### CR SOFTWARE

<table>
<thead>
<tr>
<th>crmain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Performs CR WP or RC missions</td>
</tr>
<tr>
<td>- Level Terrain</td>
</tr>
<tr>
<td>- Ascend/Descend</td>
</tr>
<tr>
<td>- Updates MR of mission progress</td>
</tr>
<tr>
<td>- Take picture and save copy to GS</td>
</tr>
</tbody>
</table>

### MR SOFTWARE

<table>
<thead>
<tr>
<th>mrmain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Determines mission file type (mis/cmd/mrcmd)</td>
</tr>
<tr>
<td>- Executes mission</td>
</tr>
<tr>
<td>- Relay commands from GS to CR</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>mrcmd</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Dock</td>
</tr>
<tr>
<td>- Take picture and save copy to GS</td>
</tr>
<tr>
<td>- Package and send to MC</td>
</tr>
<tr>
<td>- Receive/send feedback to GS</td>
</tr>
</tbody>
</table>

### GS SOFTWARE

<table>
<thead>
<tr>
<th>gsmain</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Controls MR drive mode</td>
</tr>
<tr>
<td>- Controls CR drive mode</td>
</tr>
<tr>
<td>- Monitors rover mission</td>
</tr>
<tr>
<td>- Controls sample collection</td>
</tr>
<tr>
<td>- Shuts down MR and CR</td>
</tr>
</tbody>
</table>

### CR Drive Mode

- Allows operator to command CR with STARR controls
  - Ascend/Descend
  - Dock

### MR Drive Mode

- Allows operator to command MR
- Monitors MR mission status
- Writes and sends mrcmd files to MR
- Display feedback from MR

### Docking/Picture Analysis

- Read in picture
- Determine LED centers
- Determine distance back, yaw, and side-to-side offset

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**Legacy System**

**DARE Additions**

**DARE Modifications**

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Purpose
- Critical for capturing color images
  - Requirements: R.4

Design
- COTS Webcam

Feasibility
- Legacy systems (STARR & TREADS) successfully utilized Webcams

Project Description
Critical Project Elements
Additional Elements
Summary
<table>
<thead>
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</tr>
</thead>
</table>

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FEASIBLE VS. STUDIES STILL NEEDED

- Additional testing
  - EDF
    - Maintain no slip during climb
  - Communication
    - Isolate communication system test
  - Software
    - Troubleshoot commands

<table>
<thead>
<tr>
<th>System</th>
<th>Sub-system</th>
<th>Feasible</th>
<th>Additional Analysis</th>
<th>Not Feasible</th>
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<tbody>
<tr>
<td>Surface Interaction</td>
<td>High friction wheels</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>EDF</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Locomotion</td>
<td>Wheels</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Direct drive</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Communication</td>
<td>802.11g Wi-Fi</td>
<td></td>
<td></td>
<td>X</td>
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<tr>
<td>EPS</td>
<td>On-board</td>
<td>X</td>
<td></td>
<td></td>
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<tr>
<td>Navigation</td>
<td>Encoder</td>
<td>X</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>Inclinometer</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Software</td>
<td>Build on legacy</td>
<td></td>
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<td>X</td>
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<tr>
<td>Camera</td>
<td>COTS</td>
<td>X</td>
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</table>
## Requirements Met Matrix

<table>
<thead>
<tr>
<th>Requirements</th>
<th>R.1</th>
<th>R.2</th>
<th>R.3</th>
<th>R.4</th>
<th>R.5</th>
<th>R.6</th>
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</thead>
<tbody>
<tr>
<td>High Friction Wheels</td>
<td></td>
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<td>X</td>
<td>X</td>
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<td>EDF</td>
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<tr>
<td>Locomotion</td>
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</tr>
<tr>
<td>Camera</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

| Requirement Satisfied? | YES | YES | YES | YES | YES | YES |

All requirements are met by current preliminary design
STRATEGY FOR FUTURE WORK

- **Surface Interaction**
  - Select optimal wheels
  - Select optimal EDF

- **Locomotion**
  - Determine suspension system
  - Analyze chassis for structural integrity

- **EPS**
  - Investigate additional battery packs for optimization
  - Create safety procedures

- **Navigation**
  - Choose optimal inclinometer and encoders

- **Electronics**
  - Integrate computer, Arduino, and navigation into complete circuits
REFERENCES

BACKUP SLIDES
NAVIGATION: FEASIBILITY

Using an encoder in order to determine position of CR from MR

- Encoders are not time dependent, are not distance dependent, and do not have drift due to the sensor dependence only upon radius of wheel, and the pulse count rate.

**Expected resolution BOE calculation**:

\[
\text{Feasibility of this system means resolution } < 1\text{m/count to obtain distance accuracy}
\]

- For minimum resolution of 1m/count, pulse per revolution must be calculated. With minimum diameter* found pulse/rev required would be no less than 20 pulses/rev. The pulse/rev can be chosen from a range of 1-8000 Pulses/Rev. This means the required minimum must be chosen for greater than 20P/R.

This proves usability of an encoder for a P/R greater than 20.

For known velocity = movement velocity 10cm/s, and minimum radius of the wheel gives maximum rotation rate → derive lowest possible sample rate, compare with max rate from encoders.

- Minimum frequency required for this system is .5Hz, when the sampling frequency of this studied encoder is 300KHz.

The encoder proves to be usable to determine the required distance calculations.
Rotational Distance BOE calc:
To find actual distance, the following calculation relates the software edge counting to the encoder pulse counts.

\[
\frac{D}{P} = \frac{1}{48}
\]

Autonics Sensors & Controllers, “Diameter Ø50mm Shaft type Incremental Rotary encoder,”
## MASS AND BUDGET

<table>
<thead>
<tr>
<th>Item</th>
<th>Approximate Mass</th>
<th>Qty</th>
<th>Total Mass (kg)</th>
<th>Approximate Unit Price ($)</th>
<th>Extended Cost ($)</th>
<th>Basis</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 in. diameter Wheel</td>
<td>0.075</td>
<td>4</td>
<td>0.3</td>
<td>25.00</td>
<td>100.00</td>
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<td><a href="http://www.castlecreations.com/products/mamba_max_pro.html">http://www.castlecreations.com/products/mamba_max_pro.html</a></td>
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<td>Motor Driver</td>
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<td><a href="https://store.gumstix.com/index.php/products/267/">https://store.gumstix.com/index.php/products/267/</a></td>
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<td>Arduino Mega</td>
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