# Executive Summary

The Milwaukee School of Engineering (MSOE) participates in Science Technology Engineering and Mathematics (STEM) outreach events for prospective students. The school will benefit greatly from having a sophisticated robotic control system to build excitement about STEM as well as sparking interest in fluid power, automation, and the controls fields. An agile pneumatic robot is not only a complicated control system that can be used to get young people excited about STEM, but it will also increase the prestige of MSOE knowing that a group of seniors attending the school were able to design and build the system from the ground up. In addition it also provides an exciting opportunity for future groups to iterate on the design and integrate new and exciting features.

To fulfill the needs of the project existing robot designs were researched to help determine the initial objectives and constraints for the project. Existing walking robots such as Boston Dynamics Big Dog and Little Dog, the Swiss Federal Institute of Technology (EPFL) Cheetah Cub, and various robots from the Massachusetts Institute of Technology Computer Science and Artificial Intelligence (CSAIL) laboratory were examined. These robots were used as a baseline comparison for the design specifications and constraints. From these robots a list of constraints and criteria were developed. The most critical of these are given below:

* A maximum weight of 35 kg for portability
* Maximum size of 0.75 m x 0.75 m x 1.0 m box for portability
* Custom debug panel creation to facilitate troubleshooting
* MATLAB and Simulink model support to allow mechanical engineering students to update control algorithms without knowledge of C/C++
* Electronic fuses and shielding to protect the robot and operator during use and maintenance
* Mechanical protection to reduce the risk of pinching and self-collision damage to the robot
* An easy to access emergency stop to quickly depower the robot
* A pressure relief valve to reduce the risk of overloading and damaging pneumatic components

The work done on this project is a continuation of the work done by Kevin Lee during the Research Experience for Undergraduates (REU) at MSOE. His work involved deriving a dynamic model for a simplified quadruped robot. This work is continued by the agile robotics controls team in deriving a full dynamic model for the physical robot and integrating it with control algorithms to manipulate the robot. This resulting robot design will be implemented in actual hardware by the end of the project.

Pneumatic power was chosen over electronic and hydraulic power for a variety of reasons. Pneumatics were chosen over hydraulics due to the weight and maintenance needs associated with hydraulic systems. Hydraulic systems are also dirtier than pneumatic systems and pneumatic working fluid is freely available. Pneumatics were chosen over electronic systems due to their higher power density. Electrical systems have lower power density due to the inefficiencies in converting electrical energy to mechanical work. In addition fluid power systems are compliant, meaning that if a large force is applied to the pneumatic actuators the fluid can compress and absorb the shock whereas electronic actuators will experience an increased stress.

The robot locomotion utilizes a quadruped design. Four legs were selected because of the inherent static stability of a four legged design coupled with the decreased control complexity compared to robots with five or more legs. This will allow the robot to initially actuate a slow one legged gait as the software architecture is developed, and it will eventually lead to more sophisticated gaits being developed without the need for additional hardware. The following table summarizes the advantages of legged locomotion over wheeled locomotion:

Table : Advantages and disadvantages of legged versus wheeled locomotion.

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|  | **Advantages** | **Disadvantages** |
| **Wheeled Locomotion** | -Less complex motion  -Fastest on flat ground | -Bad for rough terrain (uneven, sloped, rocky) |
| **Legged Locomotion** | -Better for rough terrain (uneven, sloped, rocky)  -Good obstacle avoidance  -Precise feet positioning | -More complex motion  -High control complexity |
| **1 Legged** | -Lower cost due to fewer components | -Complexity in controls due to static instability  -Can only hop |
| **2 Legged** | -Marginal static stability  -More achievable gaits (walk, run) | -Complex balance control |
| **4 Legged** | -Statically Stable | -Complicated leg synchronization controls |
| **More than 4 Legged** | -Statically Stable | -Very complicated leg synchronization controls  -Very high cost for additional components |
| **Hydraulic Power Source** | -Highest achievable power density | -High maintenance  -Heavy  -Dirty |
| **Electric Power Source** | -Accurate positioning | -Lowest achievable power density  -Noncompliant |
| **Pneumatic Power Source** | -Higher power density than electric power  -Low Maintenance  -Compliant action from fluid compression | -Compressible fluid causes inaccuracy in positioning |

During the previous design phase four design alternatives were drafted which fulfill the design requirements. The design alternatives were *Arachnia*, *Hexabox*, *Boxxy*, and *DogeBot*. After scoring each robot with a design matrix, *DogeBot* was chosen as the design to be continued, with a score of **96.19** out of 100.

During the current design phase mathematical models of the robot were developed to assist in determining component specifications. Initially a dynamic simulation was constructed which output the internal forces and applied torques at each joint of the robot during motion. These results were then used with a finite elements simulation to update the design of the legs and chassis.

In addition the dynamic model output was used with a motion study to determine the pneumatic cylinder bore diameter and stroke length. These values were then used to specify the maximum pressure of the pneumatic circuit, which allowed the remaining pneumatic components to be selected.

In the final design phase the selected components will be ordered and assembled by the team. The control architecture will be rapidly tested and iterated using a single leg prototype while the robot chassis and subsystems are wired and assembled. The legs will then be attached to the completed chassis to test simple gaits such as the drag. Finally, if time permits, more complicated gaits will be implemented on the robot.