Helmholtz Coils

Takis Angelides

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1 Core Task 1: Single coil (single_coil.py)

The program for the single coil is split into 3 classes: Wire, Coil and Space. Wire represents an elemental segment that is part of the coil and the Coil represents a circular coil. The Space forms the 3 dimensional space to which the Coil is placed and the magnetic field is evaluated. The code is based on the object-oriented principles and has vectorised implementations where necessary, given the high computational complexity of the simulation.

A plot of the theoretical magnetic field on the x-axis is plotted with the simulation's magnetic field and shown in Figure 1. A mean squared error for different values of n segment wires that form the coil is calculated between the theoretical solution and the simulation's solution and this is presented in Table 1 along with its plot in Figure 2. Further, in Figures 3, 4 and 5 the vector field in the x-y plane is shown for the x and y components of the magnetic field.

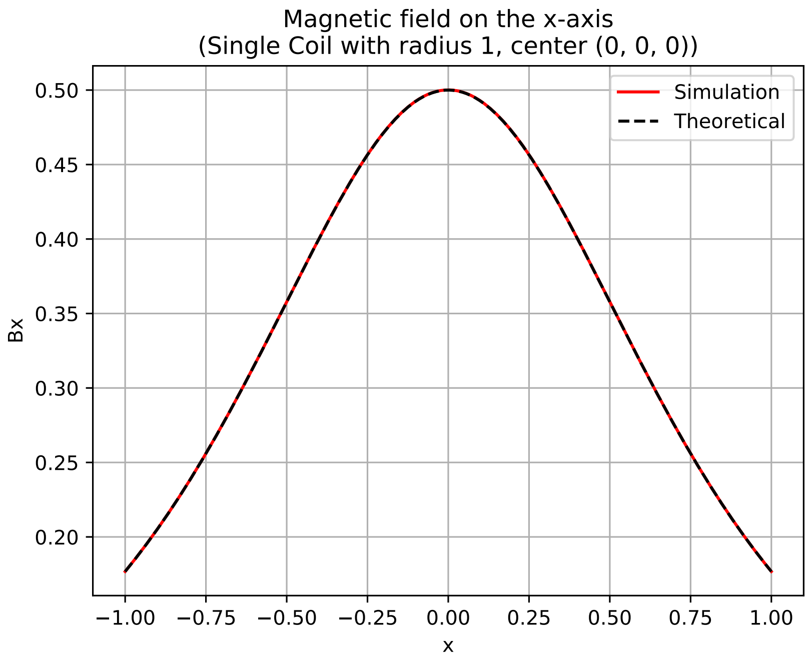

Figure 1: The simulation is found to be in excellent agreement with the theoretical expectation of the magnetic field on the x-axis.

n	**MSE**
200	0.0050418
400	0.0012604
600	0.00056016
800	0.00031509
1000	0.00020166
1200	0.00014004
1400	0.00010289
1600	0.000078772
1800	0.000062239
2000	0.000050414

Table 1: The simulation was run for different values of n to test how the number of segment wires that form the coil affect the accuracy of the simulation.

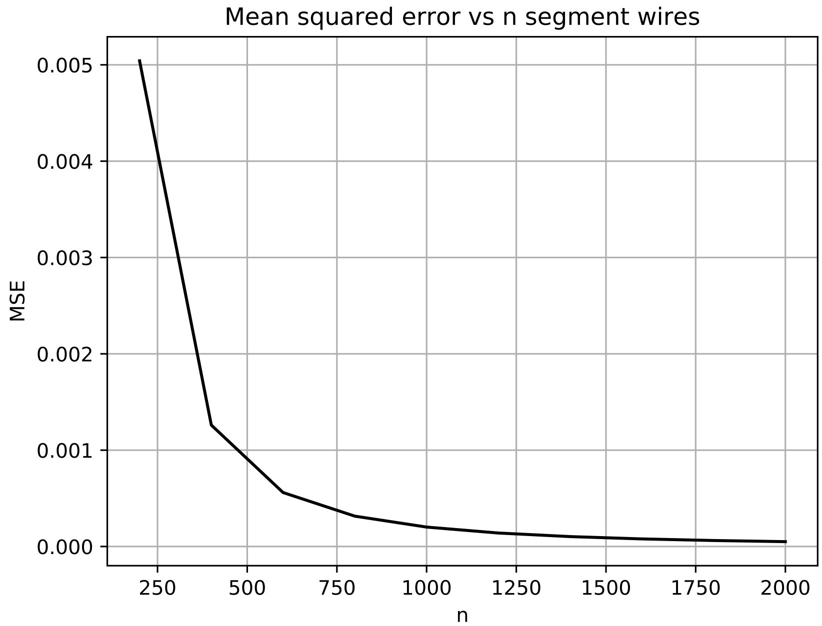

Figure 2: The MSE is seen to decrease rapidly for small n and then reduce slowly after around n = 1000. It is evident that the error of the simulation depends exponentially on n.

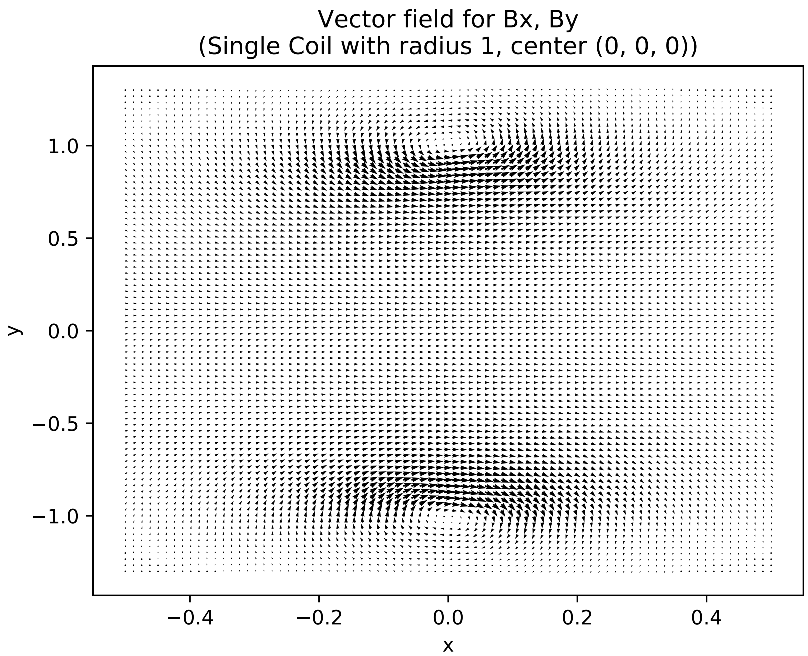

Figure 3: It is observed that uniformity is lost near the wires where the magnetic field starts to bend according to the right hand grip rule.

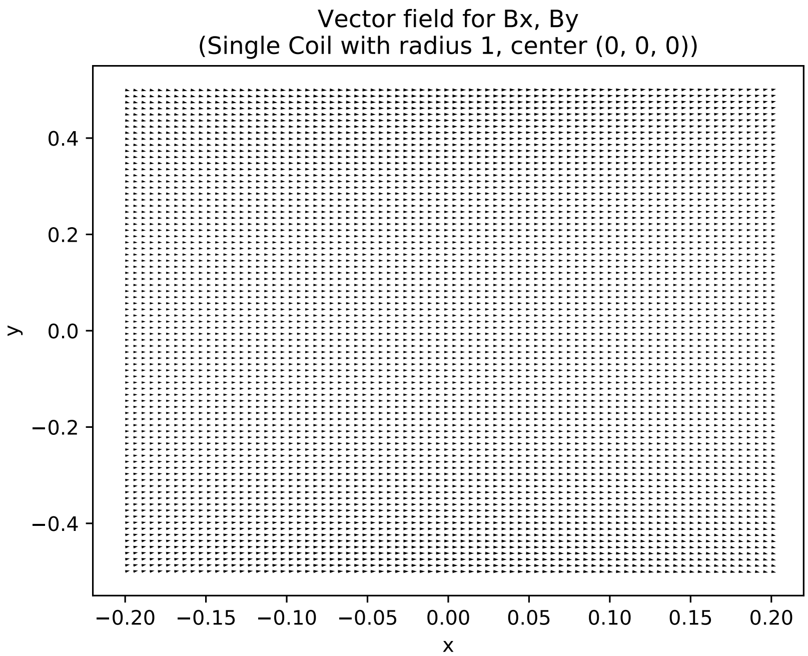

Figure 4: Towards the center and on the x-axis - which is the axis of the coil - the field is essentially uniform.

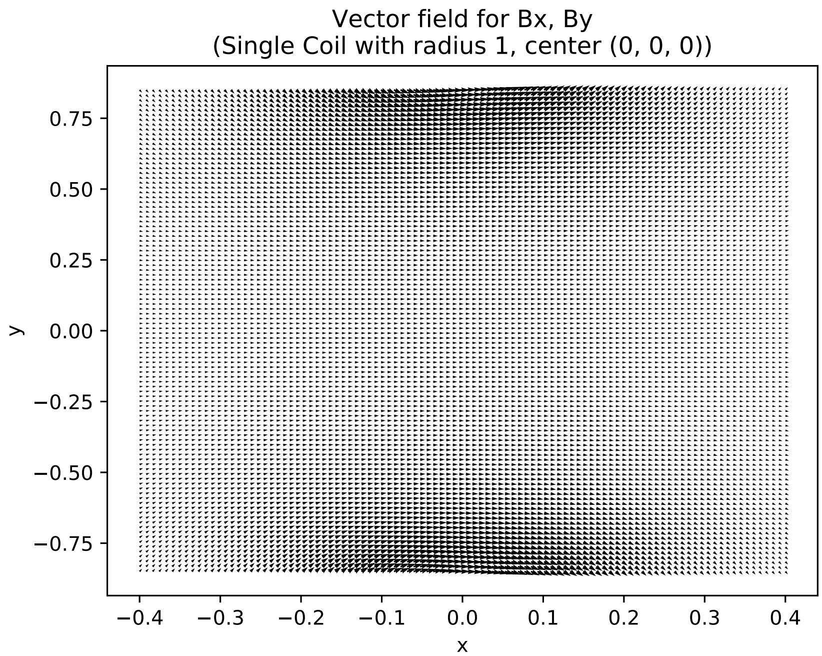

Figure 5: A closer look at the field between the wires. On the top and bottom loss of uniformity is observed.

2 Core Task 2: Helmholtz coils (helmholtz_coils.py, helmholtz_coils_2.py)

This program uses largely single_coil.py with a slight modification in the Space class so that data are generated for both coils and then added to form the final magnetic field solution. The magnetic field strength is shown in Figure 6 as a contour plot near the center of the system. The large constant contour area in the center of the plot indicates the uniformity of the field. Figure 7 displays the vector field in the x-y plane.

The second program quantifies the uniformity near the center by changing the discrete space from a cuboid to a cylinder with length and diameter of 10 cm. Then the percentage difference is found between the field strength at (0, 0, 0) and every point in the cylinder. The highest percentage difference found was 0.676%. This value depended on the number of points N in each dimension of the space created and the n segment wires. Hence the program has to calculate d**B** for $n \times N^3$ times.

The high time complexity limited the variables to n = 30 and N = 36. In Figure 8 the field strength is presented for the y-z plane and in Figure 9 the uniform vector field at the vicinity of (0, 0, 0) in the x-y plane is shown. It was noted that for lower n and N, the maximum percentage difference was higher - around 5% - and decreased rapidly as these variables were increased.

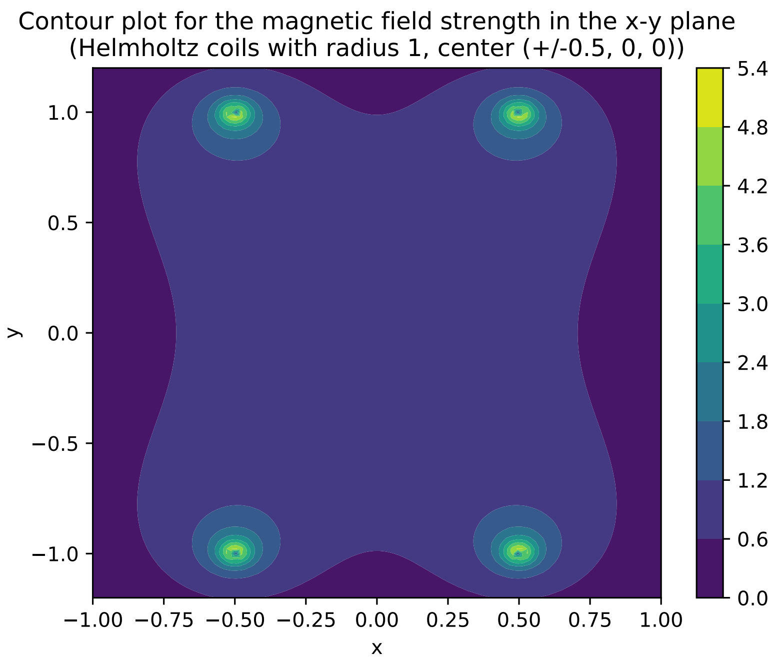

Figure 6: A large constant contour in the center of the system asserts the uniformity of the magnetic field strength in that area.

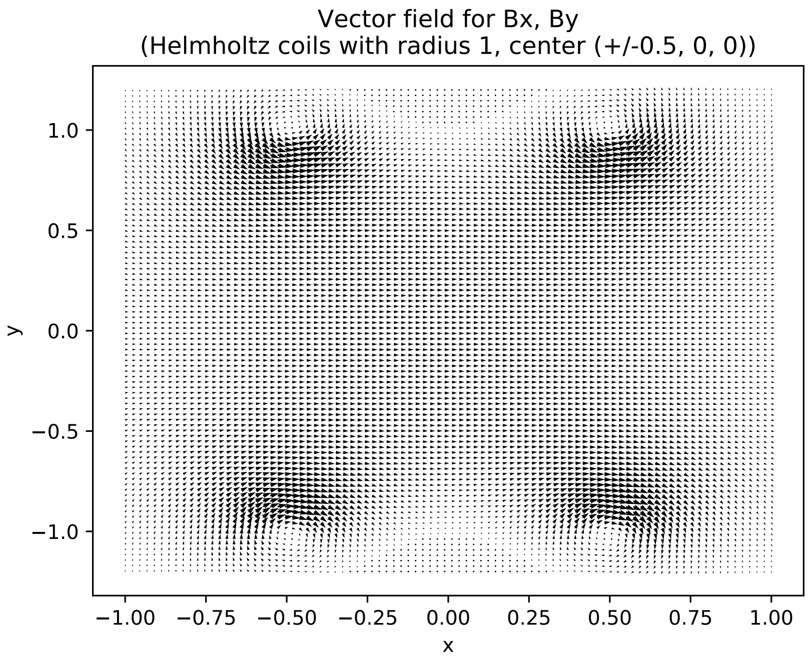

Figure 7: The vector field of components Bx, By in the x-y plane. Some non-uniformity is seen around and close to the wires, as expected.

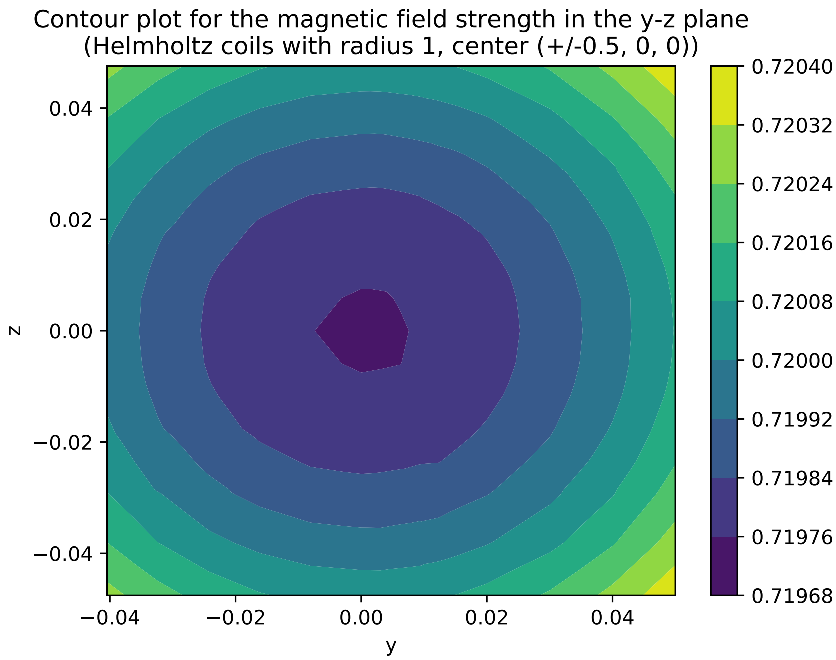

Figure 8: Contour plot down the axis of the coils in the y-z plane showing how the field strength is largely constant in the whole volume of the cylinder.

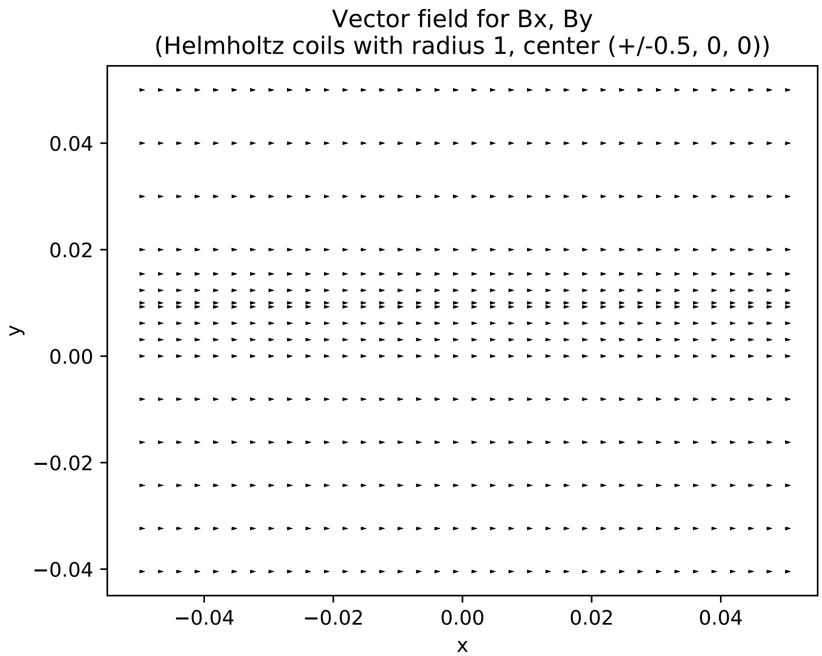

Figure 9: The vector field for components Bx, By in the x-y plane. The field is again confirmed to be uniform between the 2 coils.

3 Supplementary Task: Multiple coils (N_coils.py)

The previous calculation of the magnetic field was improved for this program so that the solution is calculated automatically by specifying just the number of coils N. The plots of the vector field in the x-y plane are produced along with magnetic field strength contour plots for different N, while keeping separation of the outermost coils fixed. The relevant figures are Figures 10 to 15. It was observed that as N increased the uniformity in the center of the system improved and the field magnitude increased.

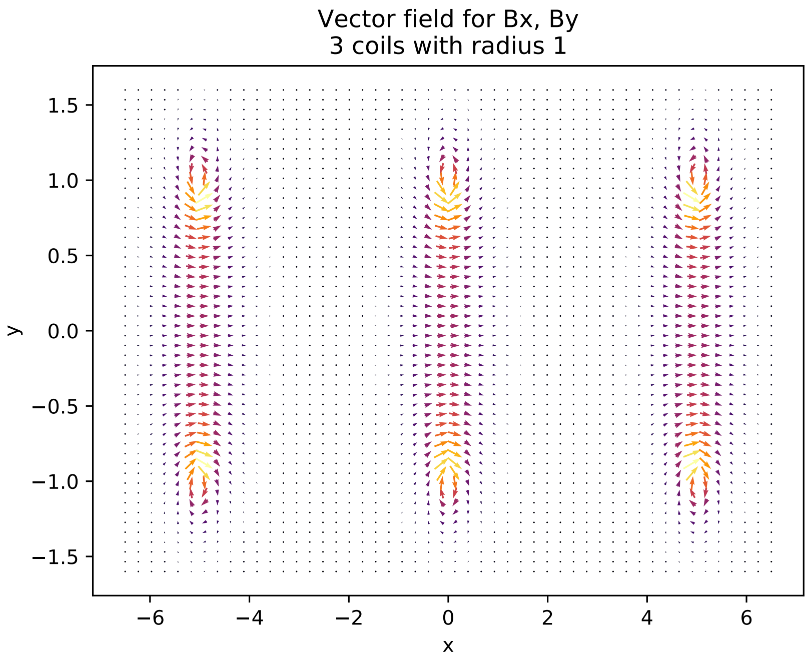

Figure 10: With a few coils, their separation is quite large and the field is similar to a single coil in each coil's vicinity.

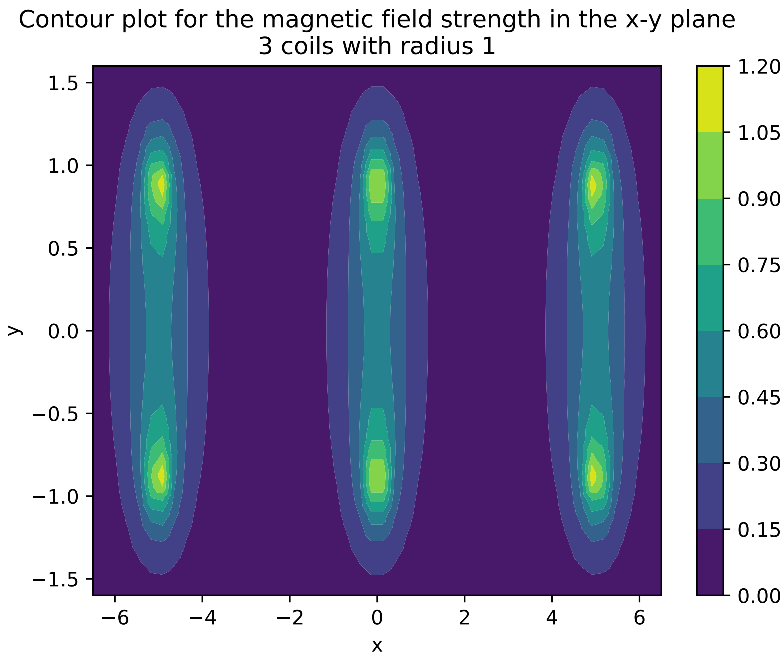

Figure 11: The field strength indicates clearly that the separation is large enough so that fields from different coils do not strongly interact.

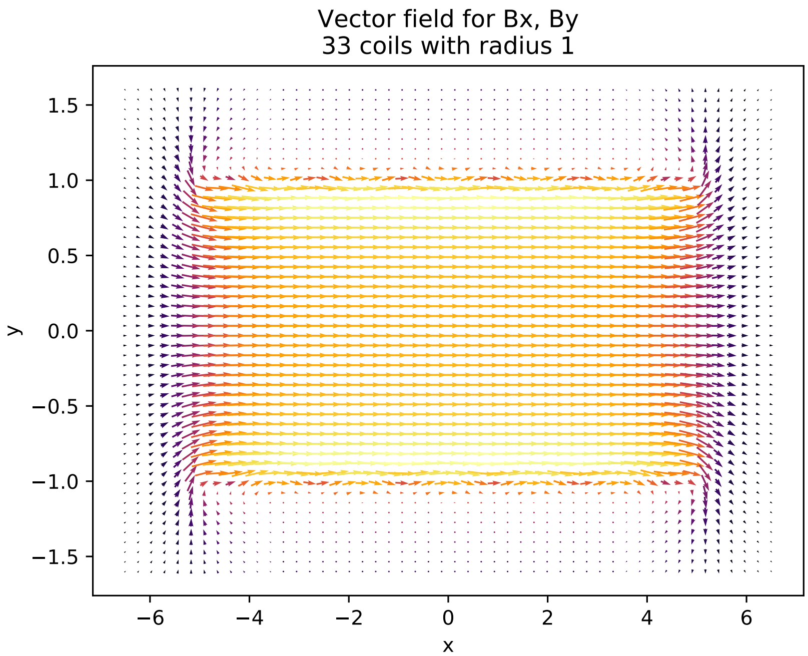

Figure 12: Increasing N improves uniformity in the middle as well as close to the wires in the cross-section of the x-y plane.

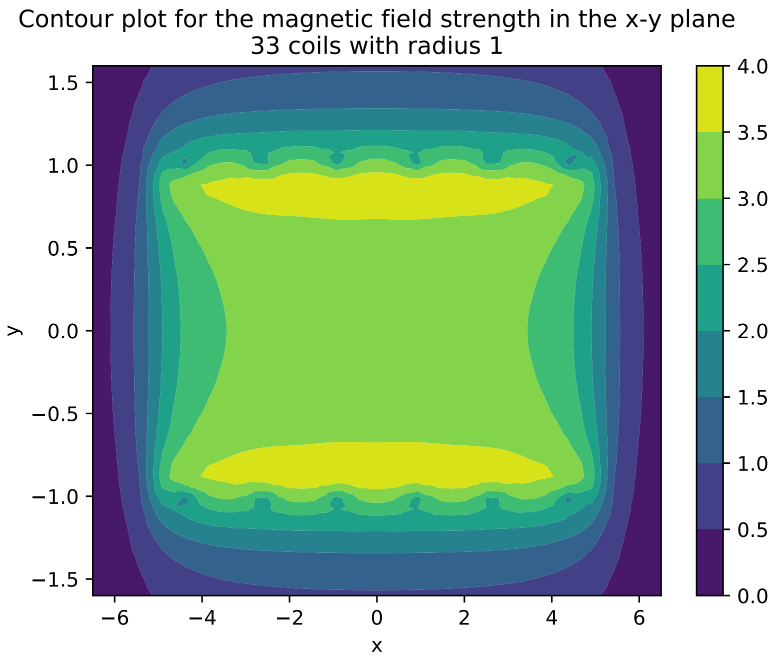

Figure 13: The field strength is seen to be uniform in the center from the large constant green contour.

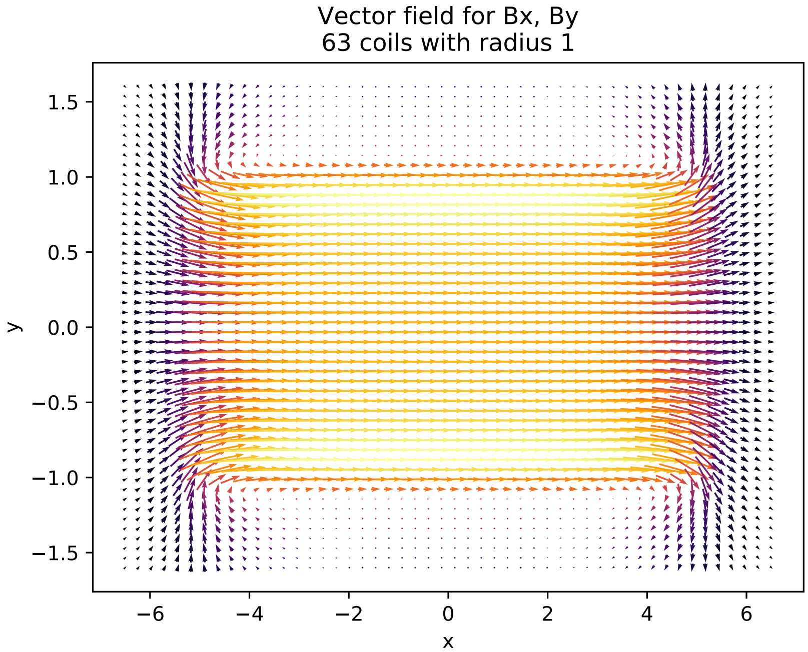

Figure 14: A large number of coils, causes their separation to be small and forces a very uniform field in the center as well as an improvement in the uniformity near the wires.

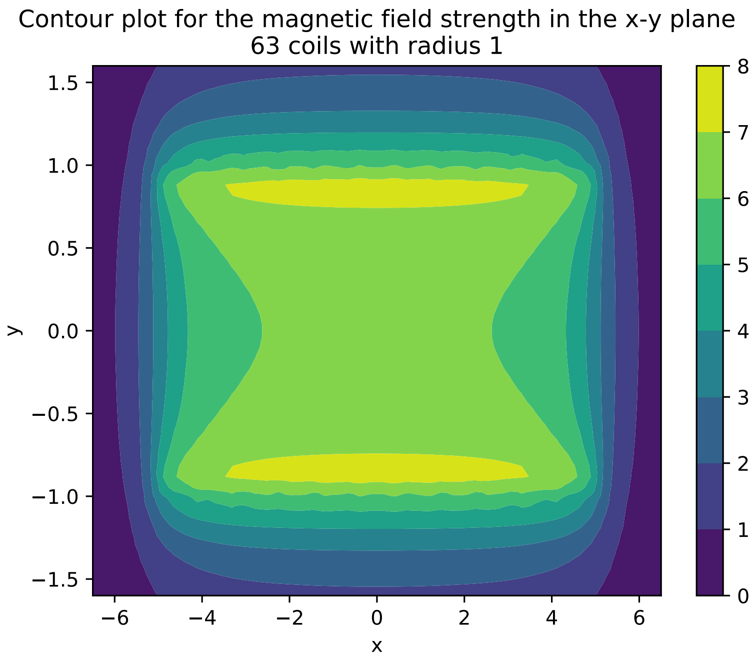

Figure 15: A very uniform field strength with a large contour in the center of the system indicates that as N increases the contours become more sharp and the magnitude also increases.