

Speed Cubing

Solving the *Rubik's Cube*

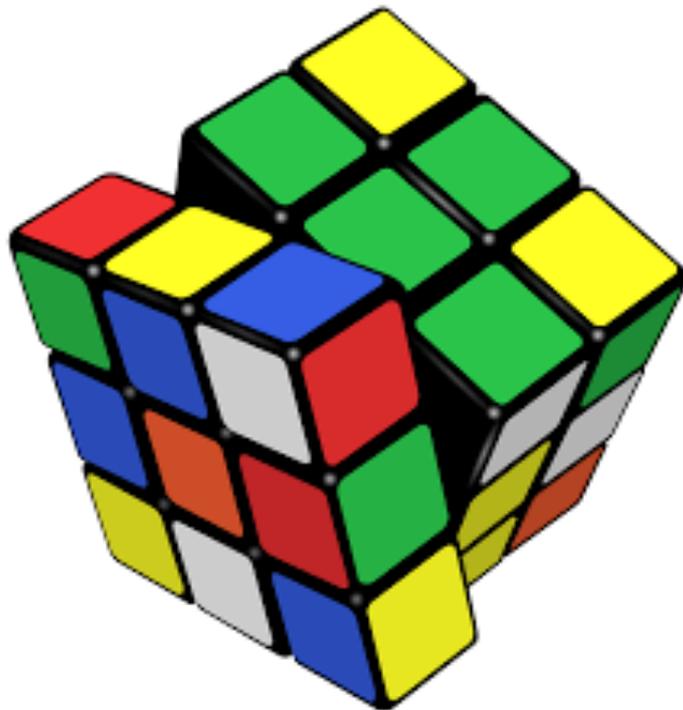
By humans and robots
What are the limits?

Gift from Rik van Grol

Article also submitted for the souvenir book

For G4G12

March 30 - April 3, 2016



Speed solving the *Rubik's Cube*

What are the limits?

by Rik van Grol, NL
Rvgr0l@hotmail.com

Introduction

The *Rubik's Cube* [1] is probably one of the world's biggest and longest lasting puzzle crazes (another one was the 15 puzzle). Everybody knows the *Rubik's Cube*. The *Rubik's Cube* was invented in the late seventies of the 20th century by Ernő Rubik, a Hungarian teacher. It was an enormous craze during the early eighties. Then during the nineties it simmered in the background, but in the twenty-first century the craze took off again. The craze is about the magical puzzle itself, the perceived complexity, the universe of Rubik's Cube variants, the analysis of its solutions, the solution methods themselves, pretty patterns made with the cube, and above all, speed solving contests. In this article I will focus on speed solving, both by hand and by robot¹.

For a long time, humans could solve the *Rubik's Cube* more quickly than robots, but for a while now, robots have been quicker. But is the comparison fair? Both humans and robots are still getting quicker. What are the limits? This article will address these issues.

My personal history with Rubik's Cube solving

The *Rubik's Cube* has many attractions. When I see an unsolved *Rubik's Cube*, anywhere, in a house, in a shop, I feel the urge to pick it up and solve it. Most of the time I can resist the urge, but even now, more than 35 years after the introduction of the *Rubik's Cube*, I still feel this urge. When I first got a hold of the *Rubik's Cube* in 1980, I was in fourth grade, and was surprised that I could easily solve the first layer, while our math teacher could not even solve a single side. Intrigued as I was, I spent a bundle (25 Dutch guilder was a lot for a 15 year old; 72 Dutch guilders in 2015) to buy my first genuine *Rubik's Cube*. At the time, solutions books were not available yet, and I solved the *Rubik's Cube* in my own way. It took me one week to reliably solve the Cube up to two remaining twisted edge pieces. It took me another two weeks to reliably solve the complete *Rubik's Cube*. Then it was interesting to compete with fellow students to solve the cube more quickly. I remember I was able to solve the cube in 1 minute 30 seconds, but I never got further – there was no competition at school and I had no contact with other cubers at the time. It was not until the end of the 80's that I got in contact with the Dutch Cube Club where there would be a traditional speed-solving contest at the yearly Dutch Cube Day. I never competed there, as I was not nearly fast enough. During the nineties the interest for speed solving in the club faded away, and it was not until 2004 that we got in contact with the rising community of speed solvers that were seeking out venues to hold their speed solving contest. Since then, they have kept one of their contests in conjunction with our yearly Dutch Cube Day. Some of the quickest human speed solvers have attended the Dutch Cube Day. I have never competed in speed solving, and my shortest solving time is still 1.5 minutes, but I am increasingly intrigued by the way the Cube is solved these days. But that is not the subject of this article.

Human or manual cube solving - speed cubing

The *Rubik's Cube* is a puzzle, meant to be used by humans. When the Cube was born, the first obstacle was how to solve it in the first place. Once that was mastered, some people became interested in producing pretty patterns, others in solving the cube as quickly as possible. When cubers came together, there would always be a friendly competition. Cubers would also exchange ideas for how to solve the Cube with the shortest number of moves. They did all of this in living room environments.

Professionalization of speed solving

¹ In Cubism For Fun (<http://CFF.helm.lu>), you find information on the other aspects of the *Rubik's Cube* craze.

So how did speed cubing develop since the eighties? To discuss this I will address a number of aspects. Speed solving started as a relaxed game, but as it became more official it needed professionalization for many aspects: timing the solving, creating the cube to solve, etc.

Registering the solving time

In the beginning speed solving would simply be done by starting at same time and noting who would be ready sooner. Then, a simple watch or stopwatch would suffice to time contestants. Soon this was not accurate enough, so within the community a special device has been developed to time cube solving. It consists of a mat and a timer (see Figure 1). The contest nowadays works as follows. The contestant gets the cube (which was covered up). As soon as the cover is lifted, the contestant is allowed to look at it for a maximum of 15 seconds². Then the contestant puts his hands on the mat. As soon as he lifts his hands off the mat, the timer starts. As soon as he has finished solving the cube, he puts both hands back on the mat, which stops the timer.



Figure 1. StackMat timer, a special timer used for speed cubing

Configuration

The *Rubik's Cube* knows 43,252,003,274,489,856,000 states, but any *Rubik's Cube* can be solved within 20 moves [2]. Many configurations can be solved in less moves (if you know which moves). So in order to keep the timing fair, it is necessary to realize that not all starting configurations are equally difficult/easy to solve quickly. In a contest, each contestant is presented with the same configuration to solved. The official world record for a single solve currently is 4.9 seconds. Because there is some luck involved in a particular cube, there is also an official world record for an average solve. Here the time is averaged over five attempts. The shortest and longest solving times are eliminated and the average of the other three is the result.

In principle, this should be fair and provide a level playing field for all contestants. The playing field might not be so level as expected. Let us assume that each configuration presented to the contestants is at maximum distance from a solved cube (20 moves)³. We can safely assume that there is no (quick) solution method (known yet) that always provides the shortest solution of 20 moves. This means that the solution method uses some strategy, which generally results in a detour before it heads for the solution. Different solution strategies are not very likely to have exactly the same length detours, which means that for each starting configuration the favourite solution strategies may be ranked. Unless all strategies are known in advance and the provided starting configurations are distributed in such a way that they favour certain solving strategies in equal frequencies, the level playing field is not really level. In reality, not all starting configurations are at max distance, and from a starting position with say 18 moves, some strategies may lead to moving away from the solution (to 19 or 20 moves) before heading for the solution, whereas others may move towards the solution more directly. It is unlikely that all of this is taken into account⁴.

Official speed records

As mentioned earlier, official records are recorded for single solves and for average solves. There are several records to be found on the Internet⁵. Most records have been achieved since 2003, only a few official records from 1982. The graph below shows the solving times over the years. Currently the records are:

² See the rules on speed cubing: <https://www.worldcubeassociation.org/regulations/#article-4-scrambling>.

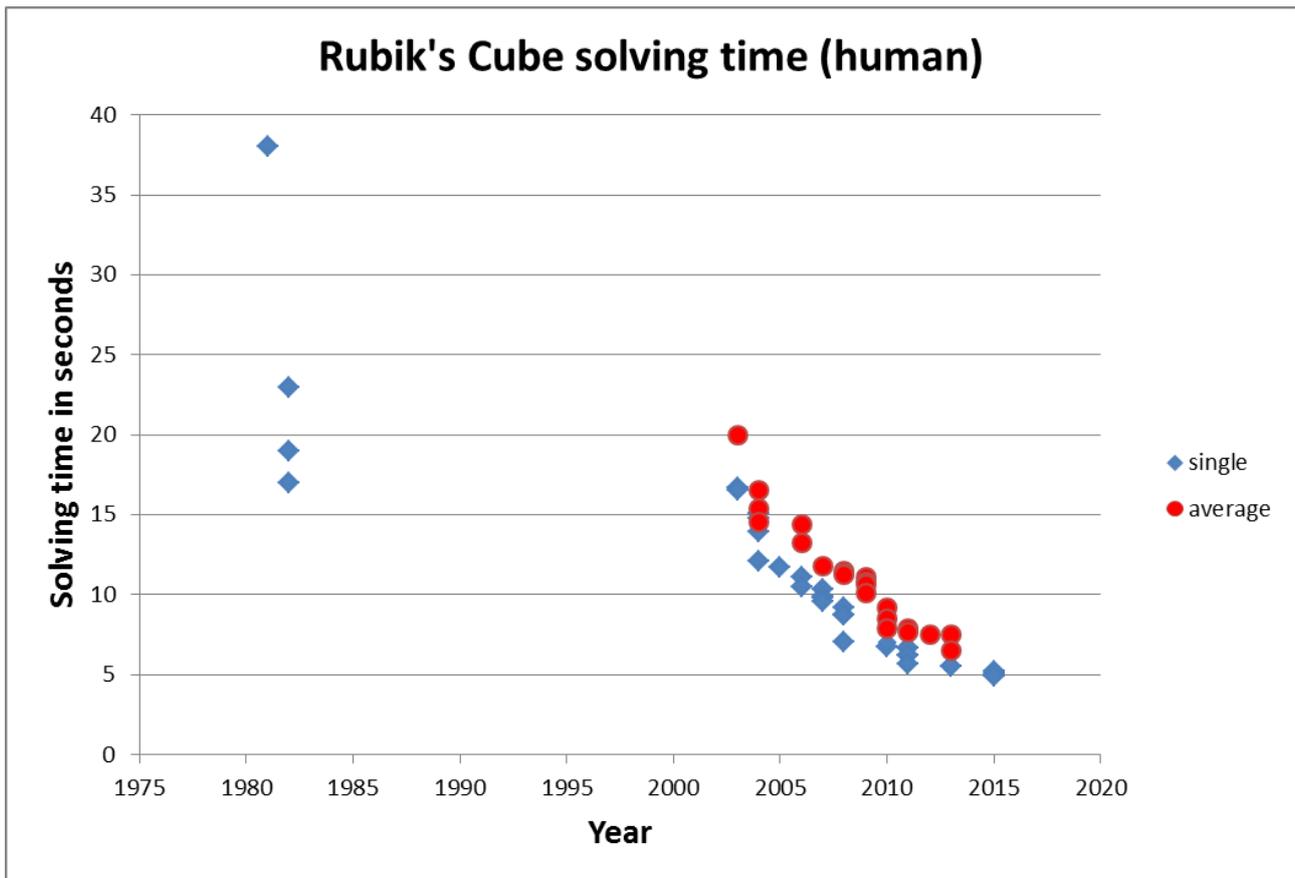
³ Based on the rules on speed cubing the scrambling is just done randomly, which does not guaranty a maximum distance configuration.

⁴ Based on the rules for speed cubing it is even 100% sure.

⁵ https://en.wikipedia.org/wiki/Rubik%27s_Cube

⁶ <https://www.worldcubeassociation.org>

- **Single** in 4.904 seconds by **Lucas Etter** (USA) at River Hill Fall in 2015.
- **Average** in 6.54 seconds by **Feliks Zemdegs** (Australia) at the Melbourne Cube Day 2013.



Mechanical or Robot cube solving

Can a *Rubik's Cube* be solved by a robot? How does solving by a robot compare to human cube solving? Who is currently better at it, and who will be the winner in the end? Those are amongst the questions I was asking myself when I came across new world records.

I have no idea when the first mechanical cube solver was constructed. For the moment I can only go by what is to be found on the Internet⁷. What is clear, however, is that mechanical (automated) cube solving required three developments:

1. a computer program capable of solving the *Rubik's cube*
2. a camera with pattern recognition software, and
3. some sort of mechanical device capable of manipulating a *Rubik's Cube*.

It is my guess that the last problem has been the easiest to solve, but was in fact the last to be realised; what is the use of a machine capable of manipulating a cube if nothing can tell it what to do? For that, you require a solution program and a way to tell in which state the cube is. Programs to solve the *Rubik's cube* were probably around quite soon after the *Rubik's Cube* became popular, but I have not been able to find any record claiming to be the first program. The first I found is from 1988, but it cannot believe it was the first. Of course next to a program, a computer must also be able to compute the solution fast enough. The enormous increase in computing power over the past decades has certainly contributed to solving that problem. The early programs required the state of the *Rubik's Cube* to be entered manually. To resemble a human solver, the robot solver must be able to "read" the *Rubik's Cube* independently. As far as I can tell, it was before 2006 that the three required components came together. Technically it could have been done sooner, but probably the new Rubik's speed cubing craze in 2003 reinitiated the interest in making robot solvers. It took a few years to get all components ready but in 2006, a first serious attempt was presented. In fact this robot, called Rubot II, looks like a human being and may

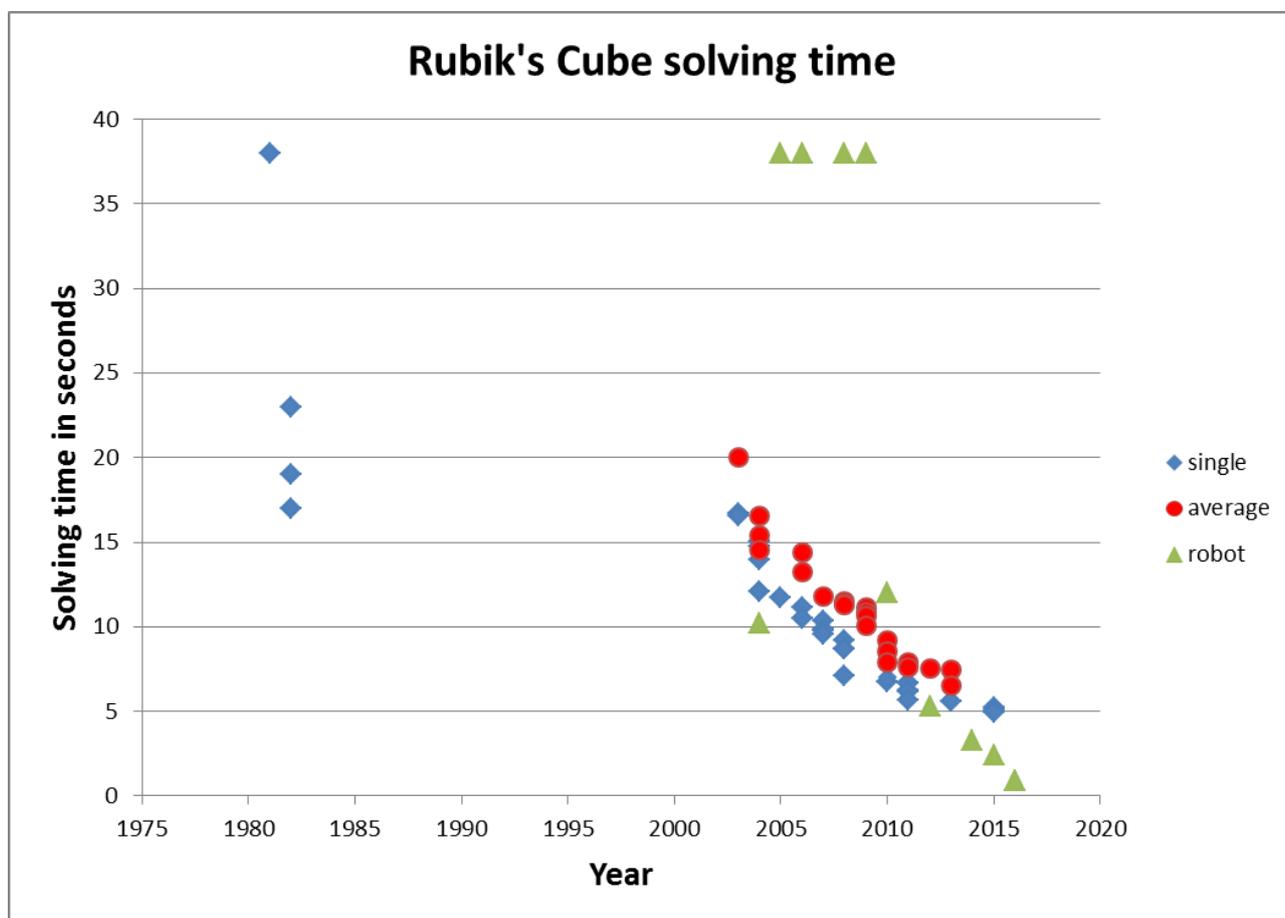
⁷ If a reader knows more, please let me know!

actually be the only version that can be compared with a human solver. This 2006 robot would pick up the cube from a table, look at it and solve it. In a video it wins against a human being: its maker. Its official speed record is 64 seconds, but this includes both the time to pick up the cube and the scanning and “thinking time”.

With 64 seconds Rubot II was in fact fairly slow, but since then robot solving has made some serious developments. It is interesting to mention that in a parallel development *Rubik’s Cube* solving robots have been developed using LEGOs. The first versions were seriously slow, and it took a bit of patience to watch. Later versions are actually amongst the quickest.

Official speed records

The speed records for Robots are less organised than those for humans, so it took quite a while to gather all of the information. In the Figure below, the Robot solving times have been added. Note that the four highest times are actually higher (60+ seconds). The time of 10 seconds in 2004 is “invalid” because this robot had no “eyes” and the solution was pre-set. This is unlike the record of 0.887 seconds, which includes scanning, thinking and solving.



3. Rubot - prototype

2006, up to 15 minutes, two arms, video camera, PC, Pete Redmond (Ireland).
Time is determined by the computing time, looking for the solution.
YouTube: *RuBot - Rubik's Cube Solving Robot Prototype*

4. Lego Rubik Utopy

2008, 61 seconds max, turntable, two holding hands, Danielle Benedettelli.
LEGO Rubik Utopia project.
YouTube: *Danny's Rubik's Cube Solver - faster than ever!*

5. Rubot II

2009, 64 seconds officially (8 pick-up, 17 scan, 39 solve), average 35 seconds, max 43 seconds
Two arms, video camera, PC, picks up the cube by itself (!).
In 2009 at the BT Young scientist and technology exhibition in Dublin, Peter Redmond developed the fastest robot to solve a *Rubik's Cube* called the Rubout 2 and it's in the Guinness book of world records. Nicknamed, "The Cubinator", this amazing robot set the Guinness World Record for a *Rubik's Cube* solving robot and appears in the 2010 Guinness Book of World Records.
YouTube: *RuBot II, The Cubinator - A Rubik's Cube Solving Robot.*

6. Lego Mindstorms

2010, minutes, Autonomous Cube solver – not a speed cuber, see Figure 2.
YouTube: *Lego Mindstorms Rubik's Cube Solving Robot.*



Figure 2. Tilted Twister LEGO
MINDSTORMS *Rubik's Cube* Solver

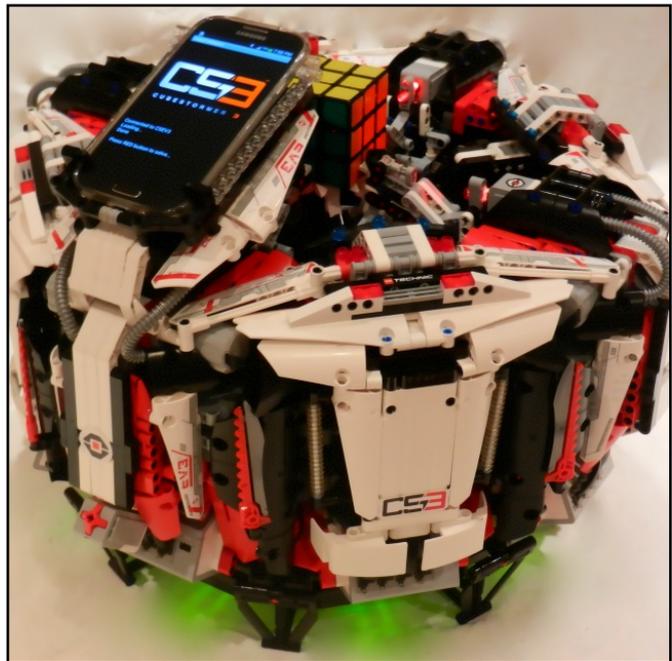


Figure 3. Cubestormer 3

7. Lego Mindstorms EV3 – Rubik's Cube Solver

2013, 95 seconds, turntable and flipper, spot-scanner, autonomous.
YouTube: *Lego Mindstorms EV3 – Rubik's Cube Solver.*

8. CubeStormer

2010, Less than 12 seconds, four arms, regular cube, Mike Dobson.
YouTube: *CubeStormer.*

9. Arduino controlled Rubik's Solver

September 2012, 16 minutes, turntable and flipper, regular cube.
This is not a speed solver but the result of a school project.

YouTube: *Arduino controlled Rubik's Cube Solver.*

10. CubeStormer 2

June 2012, **5.270 seconds**, four arms, regular cube, David Gilday and Mike Dobson, see Figure 3.
Youtube: *The CubeStormer 2 - World Record Rubik's Cube Solver made from LEGO NXT Mindstorms.*

YouTube: *This is how you solve a Rubik's cube in 5 seconds.*

11. CubeStormer 3

March 2014, **3.253 seconds**, four arms, regular cube, David Gilday and Mike Dobson

YouTube: *CUBESTORMER 3 Smashes Rubik's Cube Speed Record.*

12. Fastest robot to solve a Rubik's Cube

November 2015, **2.39 seconds**, six arms, regular cube (?), Zackary Gromko (USA).

YouTube: *Fastest robot to solve a Rubik's Cube - Guinness World Records.*

13. World's Fastest Rubik's Cube Solving Robot - Now Official Record is 0.900

January 2016, **0.900 seconds**, six arms, predrilled Rubik's Cube (!), Jay Flatland.

YouTube: *World's Fastest Rubik's Cube Solving Robot - Now Official Record is 0.900 Seconds.*

14. Fastest robot to solve a Rubik's Cube

February 2016, 0.887 seconds, six arms, regular cube, Albert Beer (Germany).

YouTube: *Fastest robot to solve a Rubik's Cube - Guinness World Records.*

Website: <http://bit.ly/GWR-RubikRobot>

Human versus or Robot cube solving

So, with 0.887 seconds versus 4.9 seconds, clearly the robot wins against the human! Or does it? I do not think it is so clear. It is like comparing apples and oranges. Let us investigate this.

Let us consider the human first (quickest and slowest alike):

- A human gets 15 seconds maximum to inspect the cube before the timing starts. The "scanning" and thinking time is not taken into account.
- The human puts the cube down and gets into the starting position (hands on the stackmat).
- The timer starts when the first hand leaves the mat and stops when the last hand is back on the mat.
- The human uses any regular cube.
- The human uses two hands (although there is also a one-handed contest).

And now for the quickest robot solver, see Figure 4:

- The *Rubik's Cube* is placed in the six arms of the Robot.
- The robot is timed from the moment that the view of the cameras is unblocked.
- The timing includes scanning, thinking and solving.
- The robot uses any regular cube (the fastest robot needs a specially prepared cube).

So is this a fair comparison?

- Two hands versus six arms.
- Only solving versus scanning, thinking and solving.
- Regular cube versus (sometimes) a specially prepared cube.
- *Rubik's cube* needs to be picked up versus *Rubik's Cube* already in solving position.

There are so many differences that it is hard to compare this in a fair way. In my view, the closest contest between human and robot has been Rubot II versus his maker (see Figure 5).

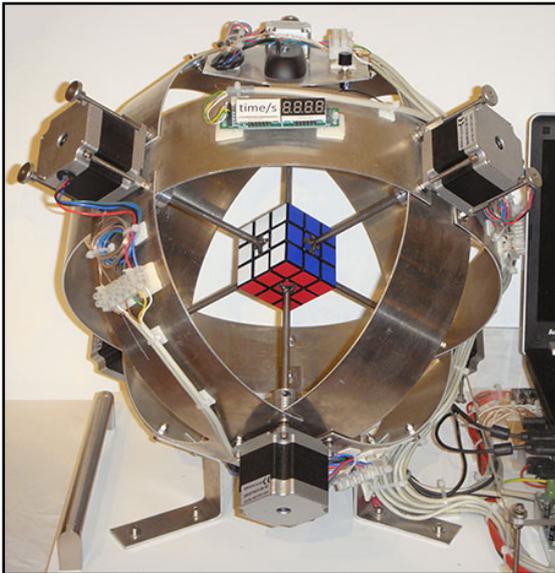


Figure 4. The fastest *Rubik's Cube* solving robot from Albert Beer



Figure 5. Rubot II battling its maker Peter Redmond

Rubot II has two arms and hands, picks up the cube, looks at it, thinks, solves the puzzle and puts it down again. This is much like a human. Strangely enough the recorded time for Rubot II includes scanning and thinking, whereas the human gets 15 seconds to do that. Even though this is the fairest comparison, there are still differences, such as the number of fingers on a hand. Still, for a fair comparison between humans and robots, Rubot II seems to be the best starting point. I do not really think this will be pursued further. I would love to see a Rubot III.

Will humans get faster? Only with better algorithms, I believe. A quick algorithm to find the solution for God's number would help. Without better algorithms, only by some luck the single solving time may decrease. This is why the single solving time should be abandoned. Only the average solving time is fair, although a larger number than five would be preferable.

Will robots get faster? With 2.39 seconds I thought the limits were nearly reached. And then weeks ago the time was more than halved! However, now mechanically the limit has probably been reached. Or has it? Obviously a better algorithm will also help here in reducing the solution sequence and thus the solving time.

I will be waiting to be surprised both by humans and robots.

References

- [1] Jerry Slocum et al., *The Cube – The Ultimate Guide to the World's Bestselling Puzzle*, 2009, ISBN 978-1-57912-805-0.
- [2] Rik van Grol, *The Quest for God's Number*, in *The Best Writing on Mathematics 2011*, Princeton University Press, ISBN 978-0-691-15315-5.