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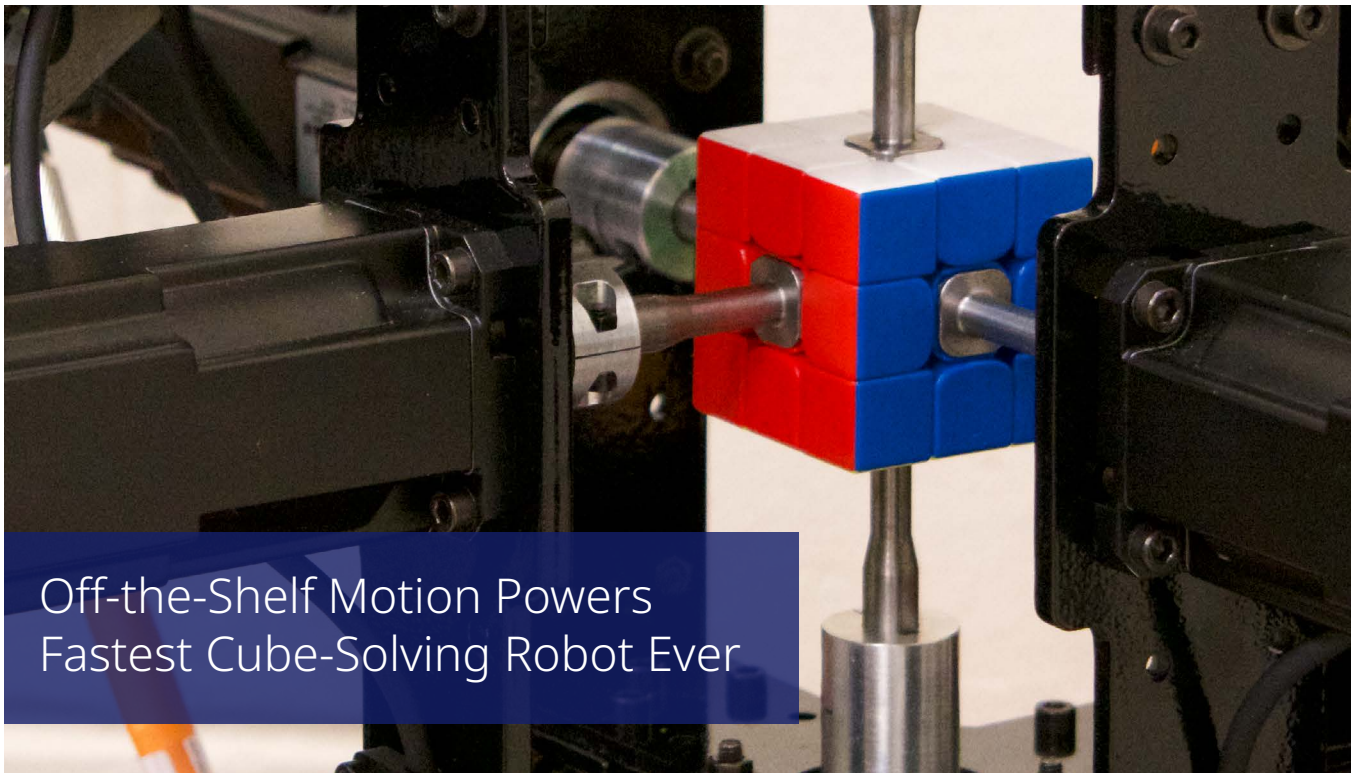


Off-the-Shelf Motion Powers Fastest Cube-Solving Robot Ever

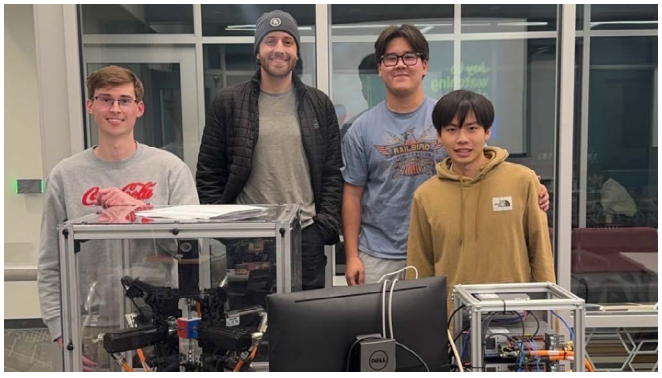
A team of engineering students set out to design and build the world's fastest Rubik's Cube-solving robot. The final system completed the task in 103 milliseconds, shattering the previous record and showcasing what is possible when high-performance motion is the foundation of the design.

Building a Rubik's Cube-solving robotic system is a test of algorithmic precision, mechanical speed and ingenuity. Many individuals, corporations and academic institutions have tackled this challenge, setting impressive benchmarks.

When Matthew Patrohay, Junpei Ota and Aden Hurd, students at Purdue University, set out to beat the world record solve time of 305 milliseconds, they knew their goal was ambitious. They also had a clear insight.

The path to record-breaking speed hinged on fast acceleration and precise control. This required sub-millisecond control loops, tightly synchronized timing, and a high-performance motion system that could deliver instant settling after each move.

Learn how the team integrated the complete Kollmorgen 2G Motion System into their design to achieve what seemed impossible: breaking a world record using off-the-shelf components.



Setting out to achieve sub-second performance

Solving a Rubik's Cube faster than the blink of an eye—in just 100 to 300 milliseconds—demands more than speed. The robot needs to complete a full sequence of moves with flawless precision by executing four critical steps in rapid succession.

First, the robot needs to capture the cube's state using cameras and a lighting setup fast and bright enough to enable reliable color detection and minimize exposure time. Next, it analyzes the data and computes an optimized solution path for fastest execution in real-time. Once the path is determined, the system then executes each move using high-speed, synchronized, multi-axis motion to drive six independent axes with controlled torque and precise timing. Typically, the robot would then settle in between moves to avoid overshoot or drift. However, the team used a strategy called corner-cutting so that the system could initiate the next turn before the previous one had finished. This required extremely fast control response and accurate feedback to keep the cube stable, even as moves overlapped.

This sequence must execute seamlessly while also accounting for real-world constraints. Vision systems, network communications and feedback loops introduce latency. Load variation occurs as cube faces rotate and forces shift between axes. Mechanical stress peaks at high speeds, especially during corner-cutting moves. Ultimately, all of this complexity must be managed while integrating third-party components to ensure that everything functions as a cohesive, reliable system.

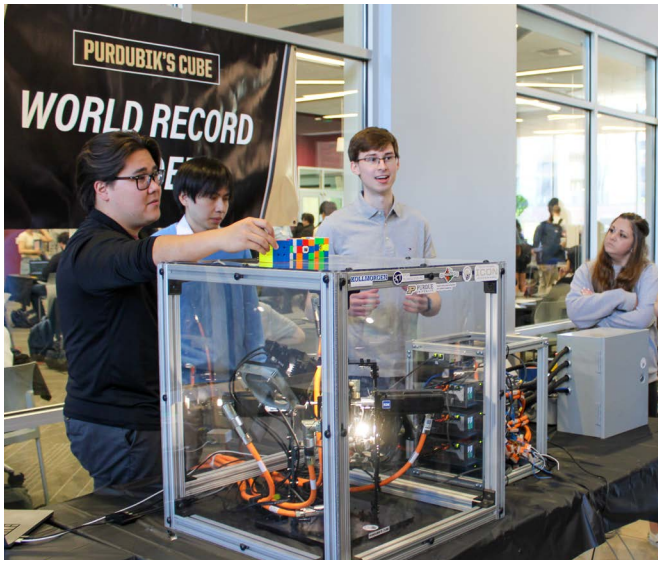
Motion becomes the make-or-break factor

From the outset, the student team recognized that their motion system would be a decisive factor in determining whether the robot could achieve record-breaking speeds. They knew they needed a complete system with high torque and low rotor inertia, capable of extreme acceleration and deceleration, guided by fast and accurate control with precise position feedback.

Why the 2G Motion System?

They evaluated hundreds of motor and drive combinations across several major vendors, comparing criteria like: torque-to-inertia ratio, control loop speed, feedback resolution, and the ability to maintain precise multi-axis synchronization without instability.

It quickly became clear that the Kollmorgen 2G Motion System—which includes AKM2G servo motors, AKD2G servo drives, and a PCMM2G motion controller—was uniquely capable of meeting these demands.



The AKM2G motors deliver exceptional torque density with low rotor inertia, enabling the aggressive acceleration and rapid reversals required for 90° and 180° cube face turns. But what set the system apart was its drive and control loop performance. The AKD2G drives feature an advanced control loop architecture with extremely fast update rates, enabling the system to correct position errors and maintain stability at speeds where other drives become unreliable. These fast update loops were critical for ensuring the robot could settle almost instantly after each move with complete accuracy.

Finally, the PCMM2G controller enabled multi-axis coordination across all six axes and complex commands. It provided synchronized motion planning, tight timing control and fast |communication with the rest of the system.

For a project that pushed the limits of mechanical and computational performance, this off-the-shelf system delivered on every level: high peak torque, low inertia, ultra-fast control loops and precise multi-axis coordination. It also allowed the team to focus on engineering the solution, confident that their motion platform wouldn't be a limiting factor.

Benefits	
AKD2G	Flexible, Easy to Use, Fast
AKM2G	Smaller Footprint, Increased Torque, Wider Speed Range, Greater Flexibility, Higher Efficiency
PCMM2G	High Performance, Seamless Integration, Plug-and-Play Capabilities

AKD2G Servo Drive

AKM2G Servo Motors

PCMM2G Motion Controller

Finding the right motion profile

With the Kollmorgen 2G Motion System in place, the team tested multiple motion profiles to determine which could deliver both speed and stability. Symmetric trapezoidal profiles accelerated quickly but often overshot at these extreme speeds. S-curve profiles reduced jerk but introduced unwanted sluggishness.

Ultimately, an asymmetric trapezoidal motion profile proved ideal. By combining aggressive acceleration with gentle deceleration, this profile enabled the motors to reach target positions faster and stabilize almost instantly, without overshoot or vibration.

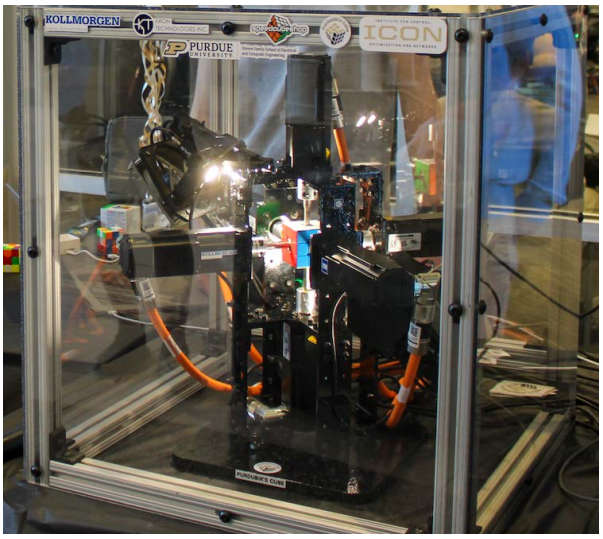
This profile paired with a strategy called corner-cutting—where the next move begins before the previous one has fully settled—shaved tens of milliseconds off the total solve time, making it one of the most impactful improvements to the motion strategy.

At this level of performance, every microsecond of latency mattered, and tight coordination across all subsystems ensured no time was lost to unaccounted delays.

Foundation for High-Speed Motion

The robot's motion began before the motors even started to move. Two high-speed industrial cameras and custom LED lighting captured and processed cube face data. Raw RGB color data converted to HSV color space for greater perceptual uniformity, mitigating variation due to brightness, shading, or camera angle. Once the vision system determined the cube's state, the solution was encoded into a compact string and transmitted via User Datagram Protocol (UDP) to the PCMM2G motion controller. The controller then parsed and executed the sequence, coordinating all six axes in real time.

System CAD Design

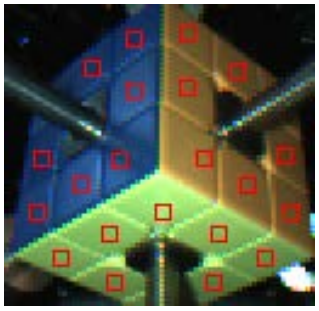


Full polycarbonate safety enclosure designed to protect operators from high-speed debris during cube operation.

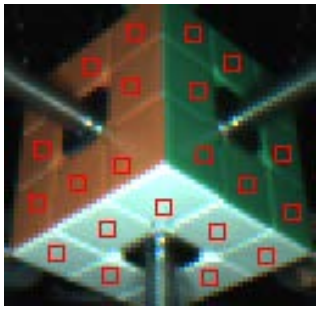
Machined Aluminum Coupler

Sls-Printed Rubik's Cube Core

The entire detection and verification process was reliably completed in under 0.25 milliseconds on average. By resolving the cube state before the first motor moved, the vision and control systems eliminated the need for recalculation mid-motion, allowing the robot to execute its path without hesitation or interruption.



Lower camera view



Upper camera view

On the mechanical side, the foundation needed to withstand the speed and precision demands. A rigid, stable frame supported high-speed actuation, enabling the motors to achieve their full torque and acceleration potential. Selective laser sintering (SLS) printed nylon cube cores and custom steel shafts improved thread retention and structural integrity. Specially engineered aluminum couplers ensured consistent alignment and optimal torque delivery. Emergency stop systems also made high-speed testing safe and repeatable.

Together, these mechanical and vision choices created a stable, predictable platform that allowed the motion system to operate at the edge of its performance envelope, delivering aggressive motion profiles with repeatable precision.

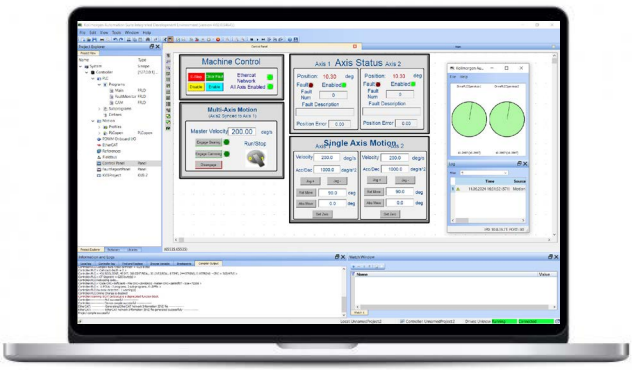
Detailed solve time breakdown		
Step	Time (ms)	Description
1	0.000	Button is Pressed - The signal is software-debounced, and as soon as it signal drops below 5V (the logic level low for the AKD2G), the official start time begins.
2	0.125	GPIO Delay - the AKD2G IO reads the signal, with 24V logic, looking for the signal level to be low (below 5V). The port used here is set to take 125 microseconds to consider the input as being off.
3	0.250	EtherCAT Delay - AKD2G informs the PCMM2G that the IO is low. The PCMM2G then turns on the LED system and informs the primary computer that the solve has started by sending a UDP "Start" signal.
4	~0.904	UDP Delay - The one-way time it takes for the "Start" UDP signal to travel from the PLC to the computer.
5	4.180	Image Acquisition time - (including communication overhead, software trigger sending, exposure time, internal camera processing, and buffer transfer).
6	0.250	Color Recognition time - determine the state of the cube.
7	0.477	Solution Generation time - determine the required turns to solve the cube.
8	~0.904	UDP Delay - The one-way time it takes to send the solution back to the PLC via UDP to be performed (telling the PLC which moves need to be performed).
9	0.250	EtherCAT Delay - communication overhead to initiate motion.
Subtotal	**7.34**	*Total pre-motion time from button press to start of motor actuation. From the oscilloscope data, we know the total here must be 7.34ms, so any approximations in steps 1-9 would fit within this value.*
10	~96.000	Motion Actuation - solve the cube.
11	0.250	EtherCAT Delay - the ADK2G informs the PCMM2G of motion completion from servo drive feedback.
12	0.050	GPIO Delay - PCMM2G logic lowers the timing output line, signaling solve complete. The ADK2G IO line used here has a 50 microsecond logic low output delay.
Subtotal	**96.051**	*Total motion execution time including signal propagation and response.*
Total	**103.391**	*Total measured solve time: button press to complete cube state. Steps 10-12 we know to be exactly 96.051 ms, so any approximations would fit within this value.*

Fast setup and seamless integration

One of the most remarkable aspects of the project was how quickly the team was able to get the system running, despite having no prior experience with industrial motion control. From the very first day, they were able to install the Kollmorgen Automation Suite Integrated Development Environment (KAS IDE) with WorkBench, a graphical user interface (GUI) to jog all six motors, confirming that the hardware was properly configured and ready for tuning.

Over the following weeks, they used KAS IDE to program the six-axis motion, synchronize the drives, and implement the custom motion profiles, all with minimal outside support. The combination of clear documentation, intuitive tools and reliable hardware meant the team could focus on engineering their solution rather than troubleshooting equipment.

In the end, they went from hardware installation to record-breaking performance in just a few weeks. This is a testament not only to their ingenuity but to the accessibility and robustness of the Kollmorgen 2G Motion System.



Breaking records with off-the-shelf components

> **With the Kollmorgen 2G Motion System at its core, the robotic system executed 21 coordinated moves in just 103 milliseconds—far surpassing the previous record.**

This achievement is the result of over a dozen iterative improvements across hardware, motion strategy and coordination. What began as a 5.1-second solve evolved into a sub-200-millisecond solve through systematic tuning, aided by high-speed cameras and a top-down tuning approach that leveraged the full capabilities of the servo motors and drives.

Every move, whether a rapid 90° or 180° turn, was completed with aggressive acceleration, instant settling and precise positioning. The robot-maintained synchronization across all six axes, handled dynamic load shifts without instability and delivered consistent, repeatable results run after run.

Most notably, the robot achieved this level of performance entirely with off-the-shelf components, proving that record-breaking motion can be achieved without custom hardware when the right technology is applied correctly.

Solve Time Progression

Solve Time (s)	Notes
5.100	First-ever functional solve.
1.560	4 minutes later—early curiosity-driven attempt to go faster.
1.290	3 minutes later—pushing further.
0.660	3 days later—still using conservative tuning and no high-speed camera.
0.475	Enabled by high-speed camera. Revealed excessive idle time between moves.
0.346	First of three solves done.
0.300	Same night—nearing world record.
0.296	Same night—broke 0.305s record using only elementary qualitative motion tuning.
0.282	Introduced custom high-strength springs and PLA cores. Improved settling time.
0.202	Introduced basic corner cutting—no motion profile changes, massive improvement.
0.178	Aggressive corner cutting tests with existing motion profiles.
0.152	Further corner cut optimization, nearing instability thresholds. SLS cores.
0.119	Rebuilt motion profile from motor limits downward. Conservative corner-cutting.
0.103	Final recorded solve. More aggressive corner-cutting.

Engineer your next breakthrough

This project proves what's possible when you focus on motion first and choose the right platform to bring it all together. With off-the-shelf components, smart engineering and a clear understanding of what matters, you can achieve exceptional performance in even the toughest applications.

Whether you're solving a unique challenge in automation, robotics or defense, you don't have to figure it out alone. Kollmorgen offers the technology, tools and support to help you design and deliver a motion system you can count on.

When you're ready to push the limits of what motion can do, we're here to help you engineer the exceptional.

Ready to move forward?

Contact Kollmorgen to discuss your needs and goals with a motion control expert for servo-driven applications.

About Kollmorgen

Kollmorgen, a Regal Rexnord Brand, has more than 100 years of motion experience, proven in the industry's highest-performing, most reliable motors, drives, AGV control solutions and automation platforms. We deliver breakthrough solutions that are unmatched in performance, reliability and ease of use, giving machine builders an irrefutable marketplace advantage.

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