

Trabajo Fin de Grado

Ingeniería Electrónica, Robótica y Mecatrónica

Autor: Jorge González Aparicio

Tutor: Manuel Gil Ortega Linares

Fabricación de prototipo de robot solucionador del cubo de Rubik

Dpto. de Ingeniería de Sistemas y Automática

Escuela Técnica Superior de Ingeniería

Universidad de Sevilla

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El tribunal nombrado para juzgar el Proyecto arriba indicado, compuesto por los siguientes miembros:

Presidente:

Vocales:

Secretario:

Acuerdan otorgarle la calificación de:

Sevilla, 2022

El Secretario del Tribunal

*A mi madre, a mi padre, a mis amigos.*

Agradecimientos

Seré breve.

*Jorge González Aparicio*

*Sevilla, 2022*

Resumen

El objetivo de este Trabajo de Fin de Grado es crear un robot que pueda resolver el cubo de Rubik, partiendo de una configuración inicial cualquiera. Hemos decidido crear una estructura envolvente, que aloja 6 motores de paso a paso, los cuales se utilizan para girar cada una de las 6 caras del cubo. Para obtener la solución del cubo, hemos utilizado una implementación del algoritmo de Kociemba en Raspberry Pi, que permite introducir el estado inicial del cubo a partir de una interfaz de usuario, y otorga una solución cuasi-óptima tras un tiempo de procesado programable. La solución consiste en una serie de caracteres que representan movimientos de las caras del cubo, el cual se orienta según un sistema de referencia basado en posiciones relativas. Esta serie de caracteres se introducen en el puerto serie del Arduino Uno encargado del control de los motores, el cual los traduce a instrucciones para los motores, y se encarga de ejecutar la solución del cubo.

Abstract

The objective of this TFG is to create a robot which can solve the Rubik’s cube from any starting configuration. We have decided to build an enveloping structure which hosts 6 stepmotors, which are used to twist each of the cube’s faces. In order to solve the cube, we’ve used an implementation of Kociemba’s algorithm in Raspberry Pi, which allows us to enter the initial state of the cube via an user interface, and produces a quasi-optimized solution after a programmable processing time. The solution consists of an array of characters, each representing a turn of the faces of the cube, which are oriented following a reference system based on relative positions. This array is then fed to the series port of the Arduino Uno tasked with the motor control, which translates it into instructions for the motors and then executes them.

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Notación

|  |  |
| --- | --- |
| Cubo/Puzle | Cubo de Rubik |
| Kociemba | Algoritmo de Kociemba |
| QTM | Métrica de Cuarto de Vuelta (Quarter Turn Metric) |
| HTM | Métrica de Media Vuelta (Half Turn Metric) |
| U | Up, cara superior del cubo/Giro de 90º en sentido horario de dicha cara. |
| D | Down, cara inferior del cubo/Giro de 90º en sentido horario de dicha cara. |
| L | Left, cara izquierda del cubo/Giro de 90º en sentido horario de dicha cara. |
| R | Right, cara derecha del cubo/Giro de 90º en sentido horario de dicha cara. |
| F | Front, cara frontal del cubo/Giro de 90º en sentido horario de dicha cara. |
| B | Back, cara trasera del cubo/Giro de 90º en sentido horario de dicha cara. |
| U′ | Giro de 270º en sentido horario de la cara superior del cubo. |
| U2 | Giro de 180º en sentido horario de la cara superior del cubo. |
| S.T.A.R. | Solver Tool for Aid with Rubik’s. Nombre asignado al robot. |
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# Introducción

In life, unlike chess, the game continues after checkmate.

- Isaac Asimov -

L

a resolución de un cubo de Rubik es un problema complejo, regido por leyes simples. Para solucionarlo es necesario memorizar algoritmos simples que provocan cambios de posición predecibles de las piezas del rompecabezas, dejando en el mismo sitio otras piezas que ya están correctamente colocadas. Siguiendo estos algoritmos paso a paso, cualquier persona puede resolver un cubo dedicando el tiempo suficiente. Esencialmente, es un problema ideal para ser resuelto computacionalmente, ya que es fácil definir todos los estados posibles del puzle. Adicionalmente, se ha demostrado que es posible solucionar cualquier estado en 26 rotaciones de 90º de las caras, o menos. Sin embargo, no es práctico obtener por fuerza bruta la solución, ya que el número de estados posibles es 43.252.003.274.489.856.000 (4.3 x 1019).[[1]](#footnote-1) A pesar de esto, se han desarrollado algoritmos que permiten solucionar el rompecabezas. Basándose en la teoría de grupos, el algoritmo de Kociemba, permite obtener soluciones subóptimas con un breve tiempo de computación, partiendo de una descripción del estado inicial del cubo.

El propósito de este TFG es diseñar y fabricar un robot que sea capaz de utilizar el algoritmo de Kociemba y de realizar el giro de las caras del cubo de forma autónoma. Dicho robot se ha bautizado como S.T.A.R. (Solver Tool for Aid with Rubik’s).

# Objetivos y Metodología

If knowledge can create problems, it is not through ignorance that we can solve them.

- *Isaac Asimov -*

E

l objetivo principal del trabajo es lograr que STAR pueda superar el mejor tiempo personal del autor para solucionar un cubo de Rubik: 1 minuto. Además, se busca lograr integrar una amplia gama de los conocimientos adquiridos en el grado, así como emplear un presupuesto lo más reducido posible.

Temprano en el desarrollo del trabajo, se decidió utilizar un enfoque modular, para poder corregir los problemas que fueran surgiendo, mientras se dejaban intactas las partes que funcionaban, casualmente siguiendo el espíritu de la forma tradicional de solucionar el cubo.

## Estado del arte.

Antes de comenzar con el proyecto, se revisó el estado del arte para tomar decisiones fundadas en ejemplos ya probados.

### Albert Beer.

Ingeniero alemán, anterior récord del mundo. Su robot Sub1 Reloaded dejó el récord en 0.637 segundos.

![Pantalla de video juego en la mano

Descripción generada automáticamente con confianza baja](data:image/jpeg;base64,/9j/4AAQSkZJRgABAQEAYABgAAD/4REURXhpZgAATU0AKgAAAAgABAE7AAIAAAAZAAAISodpAAQAAAABAAAIZJydAAEAAAAwAAAQ3OocAAcAAAgMAAAAPgAAAAAc6gAAAAgAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAEpvcmdlIEdvbnrDoWxleiBBcGFyaWNpbwAAAAWQAwACAAAAFAAAELKQBAACAAAAFAAAEMaSkQACAAAAAzg5AACSkgACAAAAAzg5AADqHAAHAAAIDAAACKYAAAAAHOoAAAAIAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA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Ilustración 1. Sub1 Reloaded, robot de Albert Beer.

### Ben Katz y Jared Di Carlo.

Estos investigadores del MIT (Massachusetts Institute of Technology) lograron en 2018 el actual récord mundial, con un tiempo de resolución de 0.38 segundos.

Imagen que contiene interior, refrigerador, cocina, pequeño

Descripción generada automáticamente

Ilustración 2. Robot de Ben Katz y Jared Di Carlo.

## Análisis del estado del arte.

En ambos casos se emplea una estructura que rodea al cubo, y 6 motores asociados a cada uno de los ejes de rotación de las caras. Ambos proyectos emplean 2 cámaras situadas en vértices opuestos del cubo para captar el estado inicial, un sistema para realizar el cálculo de la solución, basado en el algoritmo de Kociemba, y un sistema para el control de los motores.

## Módulos.

Basándonos en lo observado en el estado del arte, identificamos 4 módulos diferenciados empleados en ambos casos estudiados.

### Estructura y motores.

Las estructuras empleadas en ambos casos son metálicas y su longitud característica es en torno a 5 veces mayor que la del cubo, lo cual permite el acceso al puzle dentro del robot, así como la manipulación de este en caso de fallo, a cambio de requerir ejes de mayor longitud. Ambas estructuras son funcionalmente muy similares.

Respecto a los motores, encontramos una diferencia significativa. En el caso de Albert Beer, utiliza motores paso a paso Nema, del estilo que se pueden encontrar en impresoras 3D. Ben Katz y Jared Di Carlo utilizan motores servodisco con encóders ópticos digitales, capaces de unas aceleraciones mucho mayores. Este es uno de los puntos clave que les permitió mejorar el récord mundial.

Para este TFG, hemos decidido emplear una estructura compuesta por paneles de madera de 0.5cm de grosor, cortados a láser, para lograr un compromiso entre las distintas especificaciones del trabajo: rigidez, precisión, coste. Se ha procurado reducir el tamaño de la estructura lo más posible, para procurar reducir costes, y aumentar la rigidez.

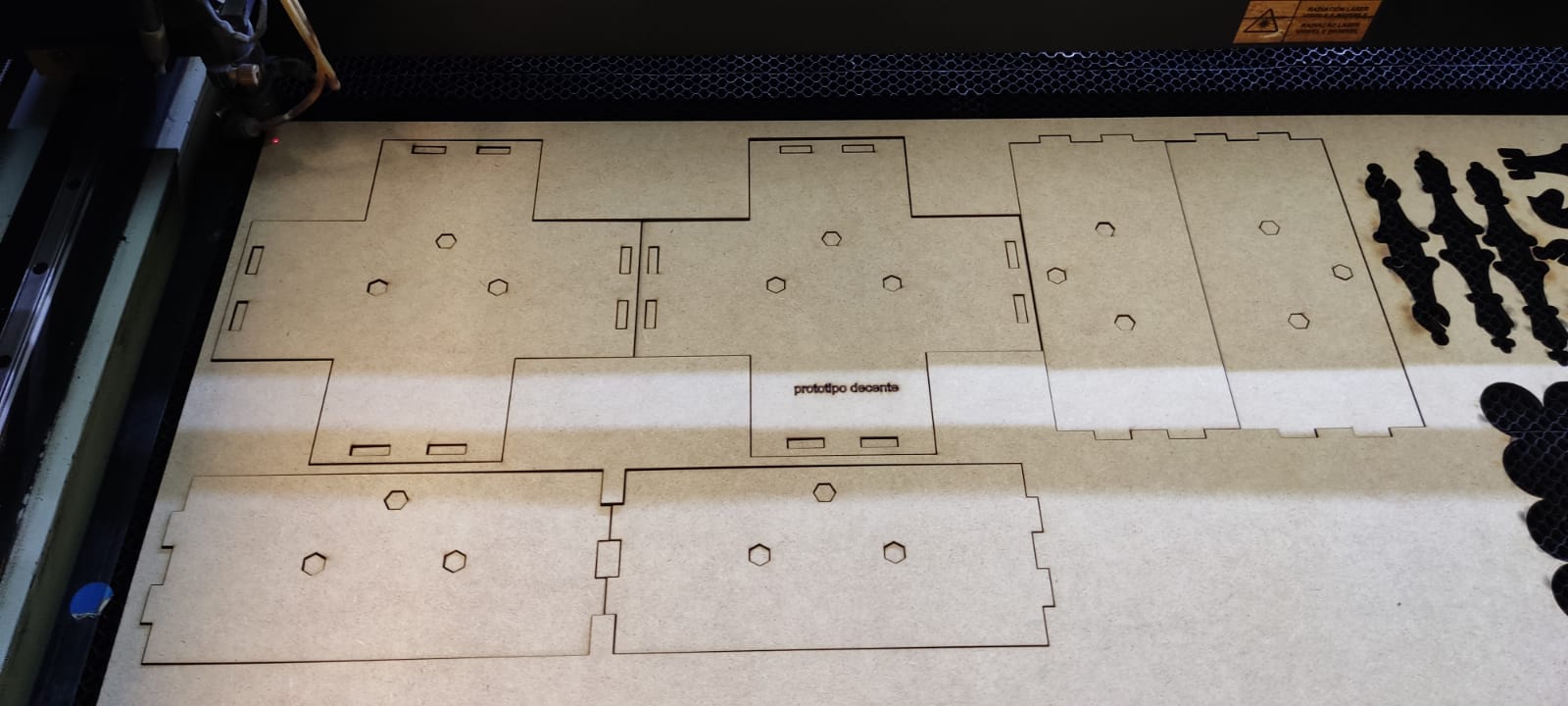


Ilustración 3. Corte de la estructura de madera.

En cuanto a los motores, se han empleado motores paso a paso, Nema 17, extraídos de una antigua impresora 3D. Teniendo en cuenta el Sub1 Reloaded de Albert Beer, es fácil ver que los tiempos de dichos motores son más que adecuados para el alcance de este TFG.

### Control de motores.

Albert Beer empleó un procesador Infeon. \*\*\*ESTABA PATROCINADO? MAS INFO\*\*\*

Ben Katz y Jared Di Carlo emplearon procesadores \*\*\*MODELO PROCESADOR\*\*\*.

Utilizaremos un Arduino Uno, con un código propio desarrollado en C, basado en un ejemplo de control de un único motor paso a paso, para recibir la cadena de caracteres que representa los giros de la solución calculada, y traducirla a las instrucciones necesarias para los motores.

### Algoritmo de Kociemba.

En ambos casos utilizaron para establecer sus respectivos récords, una implementación del algoritmo de Kociemba.

En este TFG, se utilizará el solucionador en dos fases publicado por el propio Herbert Kociemba en GitHub. Utiliza Python para realizar los cálculos, y es capaz de dar soluciones pseudo-óptimas en fracciones de segundo. Hemos empleado una Raspberry Pi 3 Model B+ para instalar el algoritmo, introduciendo en el terminal de Raspian: $ pip install RubikTwoPhase .

En el siguiente capítulo se detallarán las características de esta implementación.

### Visión por computador.

Ambos récords emplean 2 cámaras web situadas en vértices opuestos para obtener el estado inicial del cubo, detectando los colores presentes en cada una de las caras, y traduciendo su localización a una cadena de caracteres que representa el estado del cubo.

Dado que la visión por computador desempeña un papel pequeño dentro del sistema (exclusivamente comunicar al sistema que implementa el algoritmo de Kociemba el estado inicial), y sin embargo involucra múltiples problemas, incluyendo: la programación del script que analice la imagen, la iluminación del cubo de forma idéntica en cada ensayo y la configuración de múltiples cámaras en una misma Raspberry; tras varios intentos se ha decidido omitir este módulo en el TFG, optando por introducir manualmente el estado inicial del cubo usando la interfaz gráfica de usuario que incluye la implementación usada del algoritmo de Kociemba.

# Descripción del robot

The most exciting phrase to hear in science, the one that heralds new discoveries, is not “Eureka!”, but “That’s funny…”

- Isaac Asimov -

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n este capítulo se realizará una descripción detallada de los distintos componentes de STAR, así como de las decisiones relevantes tomadas durante el desarrollo del proyecto.

## Notación del cubo de Rubik

En el mundillo de los aficionados del cubo de Rubik, se suele seguir la notación Singmaster, que al tener carácter relativo, permite escribir los algoritmos de manera que pueden ser aplicados independientemente de como se asignen las caras o del color que tengan. Se utiliza: U, D, L, R, F, B, que corresponden a Up (Cara superior), Down (Cara inferior), L, (Cara izquierda), R (Cara derecha), F (Cara frontal), B (Cara trasera). Adicionalmente, a la hora de describir los giros en las soluciones, se utilizan las letras mayúsculas para indicar un giro dextrógiro de 90º de la cara correspondiente. A la letra se le añade un símbolo de prima (′) para indicar un giro levógiro de 90º, y colocar un 2 detrás de la letra indica un giro de 180º.

## Software.

El software que controla el comportamiento del robot se divide en dos partes claramente diferenciadas:

### Implementación del algoritmo de Kociemba.

Tras la instalación del GitHub de Herbert Kociemba, se descargaron en la Raspberry Pi las tablas que permiten el funcionamiento del algoritmo. Para utilizar la implementación, es recomendable iniciar un servidor local en un terminal en Python, con los comandos:

>>> import twophase.server as srv

>>> srv.start(8080, 20, 2)

Y luego abrir la interfaz gráfica de usuario que permite introducir cómodamente el estado inicial del cubo, con el comando:

>>> import twophase.client\_gui

Desde la interfaz gráfica se puede copiar el estado inicial, y al pulsar el botón “Solve” se obtiene la solución del cubo.

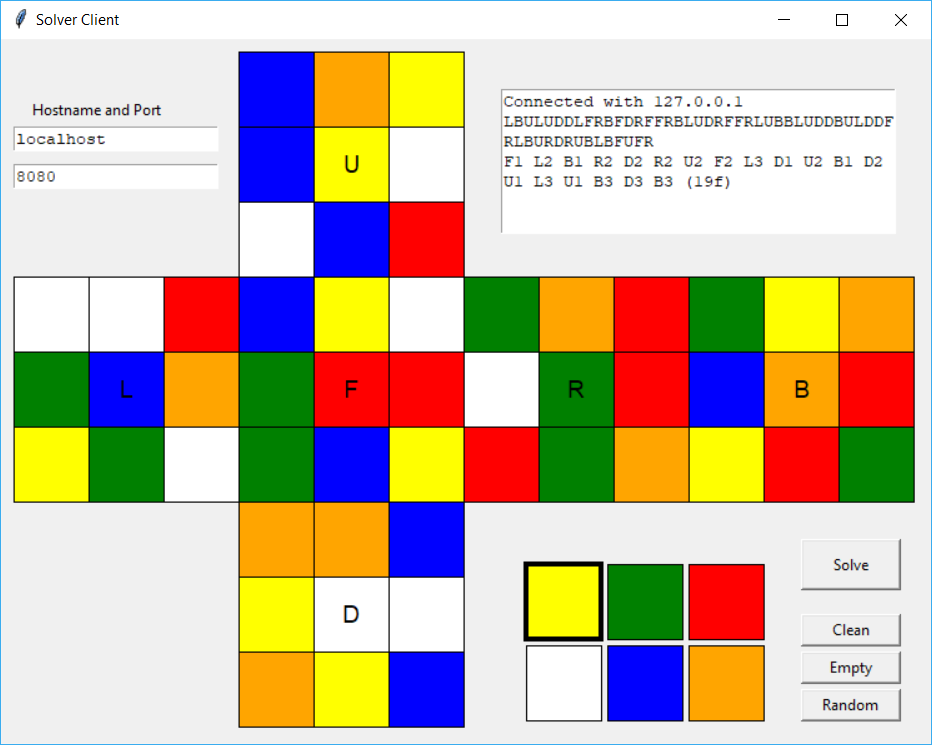


Ilustración 4. Interfaz de usuario.

En el caso de cometer un error al introducir el estado inicial, que hiciese que el cubo fuese irresoluble, porque el número o colocación de los cuadrados de colores fuese incorrecto, al pulsar Solve la interfaz señalaría que no es posible obtener una solución.

\*\*\*FOTO ERROR SOLUCION NO POSIBLE\*\*\*

### Control de motores.

Se ha creado un código en Arduino que recibe por puerto serie la solución con el formato establecido, y traduce dicha solución a instrucciones para los motores.

\*\*\*REDACTAR MÁS, INTRODUCIR PARTES CLAVE DEL CÓDIGO, AÑADIR FOTOS\*\*\*

## Hardware.

Se han utilizado:

* Cubo de Rubik.
* Raspberry Pi 3 Model B+.
* Periféricos (ratón, teclado, monitor/pantalla).
* Arduino Uno.
* Fuente de alimentación.
* Motores Nema17
* Drivers A4988
* Estructura de madera realizada por corte láser.
* Piezas personalizadas modeladas en Catia y fabricadas por impresión 3D.

### Cubo de Rubik.

Se ha comprado un cubo económico, de la marca \*\*\*MARCA\*\*\*. Permite acceder a los tornillos que sujetan el núcleo a través de las tapas de las piezas centrales.

### Raspberry Pi, periféricos.

Se ha escogido una Raspberry Pi ya que cumple con los requisitos mínimos para utilizar la implementación de Herbert Kociemba Los periféricos utilizados han sido cedidos por el FABLAB, incluyendo ratón, teclado y minipantalla compatible con Raspberry Pi.

### Arduino Uno.

Aunque inicialmente se escogió un Arduino Mega, tras realizar el conexionado se observó que los pines digitales del Arduino Uno eran suficientes para controlar los motores gracias a los drivers escogidos. \*\*\*DETALLE CONEXIÓN PINES ARDUINO\*\*\*

### Fuente de alimentación.

Para dar tensión a los motores es necesario una fuente de 12V. Al disponer de una fuente programable, la hemos utilizado también para alimentar el Arduino y la Raspberry Pi. Se muestran a continuación todas las conexiones realizadas: \*\*\*IMAGEN CON ESQUEMA DE CONEXIONES, PAGINA DE PRACTICAS ARDUINO\*\*\*

### Motores, drivers.

Se han reutilizado los motores Nema 17, así como los drivers, que pertenecían a una antigua impresora 3D del FABLAB de Sevilla. \*\*\*AÑADIR CARACTERÍSTICAS DRIVERS, COMPLETAR CON FRAGMENTO CODIGO DE CONTROL\*\*\*

### Estructura de madera.

El FABLAB permite a los estudiantes de la Universidad de Sevilla el uso de sus instalaciones para todo tipo de proyectos académicos. Así pues, se empleó la cortadora láser de la que disponen para obtener la estructura que se utiliza en el proyecto. \*\*\*FOTOS ESTRUCTURA MONTADA, VIDEO CORTE\*\*\*

### Piezas 3D.

Uno de los primeros problemas que hubo que solucionar al comienzo del proyecto, fue como enlazar las caras del cubo a los ejes de los motores. Con ese propósito se diseñaron unas agarraderas a medida que encajan en el hueco presente tras levantar las tapas de las piezas centrales, y que conectan con el eje de los motores, permitiendo el giro solidario de las caras con los ejes.

\*\*\*FOTOS\*\*\*

Adicionalmente, se diseñaron unos enganches para asegurar los motores a la estructura de madera, empleando tornillos y tuercas.

\*\*\*FOTOS\*\*\*

## Funcionamiento.

Una vez se ha encendido la alimentación, el primer paso para usar STAR es utilizar el monitor serie del Arduino para mezclar el cubo. Una vez se ha llegado a una mezcla aceptable, se debe utilizar la interfaz de usuario de la implementación de Kociemba para comunicar el estado inicial del cubo. Tras pulsar el botón “Solve” se obtienen los movimientos a realizar. Esta solución se introduce en el monitor serie del Arduino Uno, y tras enviarlo, S.T.A.R. comienza a mover las caras automáticamente.

\*\*\*INTRODUCIR GUÍA PASO A PASO CON ILUSTRACIONES\*\*\*

Debido a la naturaleza acumulativa de los errores de posición de los motores en la ejecución, es aconsejable agrupar los giros de la solución en grupos de 3, y comprobar que los giros se ejecutan correctamente antes de enviar el siguiente grupo al monitor serie.

# Resultados

Part of the inhumanity of the computer is that, once it is competently programmed and working smoothly, it is completely honest.

- Isaac Asimov -

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olviendo a los objetivos señalados al principio de esta memoria, se debe comprobar si S.T.A.R. cumple con ellos.

## Tiempo de resolución.

Se ha logrado solucionar el cubo en menos de un minuto. El principal problema para lograr un tiempo más rápido es la construcción de la estructura, el cubo escogido, y, mayormente, el hecho de que la posición de los motores se controla con un lazo abierto. \*\*\*ENLAZAR VIDEO\*\*\*

## Presupuesto.

El presupuesto total del trabajo es: \*\*\* HACER LOS CALCULOS + ESTIMACION PARA PUBLICO\*\*\*.

## Conocimientos integrados.

Se han utilizado conocimientos de electrónica, programación en C, uso de GitHub, diseño en 3D. No solo se han aplicado conocimientos previos, sino que se han descubierto nuevas herramientas que se emplearán en futuros protectos. \*\*\*PENSAR, REDACTAR.\*\*\*

# Ampliaciones

Education is not something you can finish.

- Isaac Asimov -

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n el transcurso del proyecto se ha decidido dejar de lado algunos aspectos, por complejidad o falta de tiempo. En este capítulo se señalan los esfuerzos realizados para que puedan ser considerados en el caso de querer ampliar el trabajo realizado.

## Visión por computador.

Se ha intentado repetidas veces hacer funcionar el módulo de visión por computador que incluye la implementación en GitHub del algoritmo de Kociemba, sin embargo no se han logrado resultados consistentes, a pesar de realizar múltiples pruebas bajo una iluminación constante proporcionada por una lámpara LED de color blanco, y a pesar de haber modificado, siguiendo las indicaciones presentadas en el GitHub, los parámetros que controlan el módulo en la interfaz que lo acompaña. \*\*\*FOTOS DE LA VISION POR COMPUTADOR FALLANDO\*\*\*.

Uno de los factores que ha influido en el mal resultado de la visión por computador, puede haber sido el uso de una cámara inadecuada. Se realizaron las pruebas con un módulo de cámara de bajo coste, compatible con la Raspberry Pi. Otro factor que se ha observado, es que las pegatinas del cubo comprado reflejan bastante luz, provocando errores en el módulo de visión.

\*\*\*HABLAR DE ILUMINACION, COLORES DEL CUBO COMPRADO, VISION DE PYTHON DEL GITHUB, POSIBLES SCRIPTS, PERO PROBLEMAS PARA PASAR DE LOS SCRIPTS AL SOLUCIONADOR…\*\*\*.

## Conexión por puerto serie.

Para realizar la conexión de la Raspberry Pi con el Arduino Uno, se han considerado diversas opciones. Desde emplear el programa PuTTY tras instalarlo en la Raspberry Pi, hasta hacer una conexión directa de los pines de ambas placas y crear un script que envíe la solución a través de comandos en un terminal en Raspian.

Finalmente, ya que se puede instalar la IDE de Arduino en la propia Raspberry Pi, se ha optado por omitir la conexión automática, en favor de introducir la solución a través del monitor serie de Arduino.

\*\*\*PROBLEMAS CON SDs DE RASPI, DIFICULTAD DE EXTRAER LA SOLUCION DEL SOLUCIONADOR AUTOMATICAMENTE. LA CONEXIÓN DE RASPI CON ARDUINO NO ES EL MAYOR PROBLEMA, PERO ES LO MISMO ESCRIBIR EN PuTTY QUE ESCRIBIR EN EL MONITOR SERIE DE ARDUINO.\*\*\*

## Observaciones adicionales.

El tiempo logrado en el trabajo es mucho mayor al mínimo teórico alcanzable por STAR. Sin embargo la calibración de los parámetros es un trabajo tedioso y los errores de los motores y de alineación del cubo en la ejecución de la solución se acumulan hasta provocar que se bloquee STAR o que se salte uno de los giros de la solución, haciendo que el resultado final no sea el cubo resuelto. Revisando la estructura, y probando con distintos niveles de soltura del núcleo del cubo, debería ser posible lograr una mayor consistencia en la ejecución. Emplear un cubo de mayor precio, que incluya imanes de neodimio para facilitar la alineación, podría contribuir a evitar los errores en la resolución. Adicionalmente, el empleo de un bucle de control cerrado con motores paso a paso asociados a encóders, u otro tipo de tecnología que permita eliminar el error de la posición de los motores en régimen permanente, permitiría reducir o incluso eliminar por completo los fallos descritos.

# Referencias

# **Índice de Conceptos**

conceptos 9

# **Glosario**

ISO: International Organization for Standardization 4

UNE: Una Norma Española 4

1. Si se tiene en cuenta la orientación de los centros, el número de estados asciende a 88 580 102 706 155 225 088 000 (8.9 × 1022). En el puzle original, y en este trabajo, no se consideran los giros de los centros. [↑](#footnote-ref-1)