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| PROIECT INGINERIA REGLARII AUTOMATE II | | | | | |
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**Twin Rotor System**

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# Scopul Proiectului

Scopul acestui proiect este de a dezvolta un control robust pentru viteza de rotație a unui sistem cu două elice (twin rotor) și de a îmbunătăți robustețea acestuia. Controlul unui astfel de sistem prezintă o serie de provocări specifice, datorită naturii sale complexe, neliniare și interdependenței dinamice dintre componente.

Sistemele twin rotor prezintă un comportament puternic neliniar, cauzat de dinamici complexe, cum ar fi cuplul giroscopic, variațiile în rezistența aerodinamică și eficiența rotoarelor care depind de viteza de rotație și unghiul de atac. Aceste nelinearități complică semnificativ procesul de modelare și control al sistemului.

Fiind un sistem cu două intrări și două ieșiri (MIMO - Multi-Input Multi-Output), fiecare elice influențează fluxul de aer și performanța celeilalte. Această interacțiune aerodinamică duce la efecte de cuplare puternice, ceea ce face dificilă controlarea independentă a fiecărei elice fără a lua în considerare influențele reciproce.

Sistemele twin rotor sunt extrem de sensibile la perturbații externe, cum ar fi rafalele de vânt sau variațiile în densitatea aerului. Aceste perturbații pot afecta semnificativ stabilitatea și performanța sistemului, impunând cerințe stricte asupra algoritmilor de control pentru a menține stabilitatea în prezența incertitudinilor și a variațiilor neașteptate.

## Obiective

- identificarea sistemului

-validarea modelului identificat

-aplicarea tehnicii de decuplare

-calcularea regulatoarelor

-testarea si implementarea regulatoarelor pe sistemul real

## Specificații

Prin acest proiect, îmi propun să controlez vitezele de rotație ale celor două motoare de curent continuu pe care sunt atașate elicele. În prima etapă, voi identifica modelul matematic al acestui sistem cu două elice. Pentru controlul sistemului, voi utiliza un regulator pentru fiecare motor în parte. Obiectivul final al proiectului este de a obține performanțe superioare față de cele ale sistemului inițial.

Având în vedere că sistemul prezintă două intrări și două ieșiri (MIMO) acesta constituie o provocare semnificativă, în special datorită lipsei de experiență anterioară cu astfel de sisteme. Intenționez să aplic metode riguroase de modelare și control, astfel încât să ating performanțele dorite și să dezvolt o înțelegere aprofundată a controlului sistemelor MIMO.

# Determinarea modelului matematic al sistemului

## Analiza sistemului

1. **Mărimi Controlate**:

* Vitezele de rotație ale motoarelor: Acestea reprezintă mărimile pe care dorim să le controlăm în sistem. Stabilirea și menținerea unor viteze de rotație specifice ale motoarelor sunt esențiale pentru controlul poziției și orientării sistemului twin rotor.

1. **Mărimi Manipulate**:

* Tensiunile de alimentare ale motoarelor: Acestea reprezintă mărimile pe care le putem ajusta pentru a controla vitezele de rotație ale motoarelor. Prin modificarea tensiunilor de alimentare, putem influența vitezele de rotație ale motoarelor și, implicit, comportamentul sistemului twin rotor.

## Achiziție semnale

Two Rotor Aero-dynamical System (TRAS) este un echipament dezvoltat de INTECO, utilizat pentru testarea și verificarea sistemelor de control în cadrul laboratoarelor. Acest sistem constă din două motoare la care sunt atașate două elice și o bară de metal care leagă cele două motoare. Sistemul este montat pe o tijă care previne prăbușirea, dar permite rotația în două direcții (dispune de o cuplă cinematică de gradul IV). Cele două motoare sunt denumite pitch și azimuth. Motorul pitch este utilizat pentru mișcarea în plan vertical, iar motorul azimuth este utilizat pentru mișcarea în plan orizontal. Sistemul dispune de două intrări, câte una pentru tensiunile aplicate motoarelor, și patru ieșiri: două pentru vitezele de rotație ale motoarelor și alte două pentru pozițiile unghiulare ale barei de metal.

## Identificare / Modelare analitica

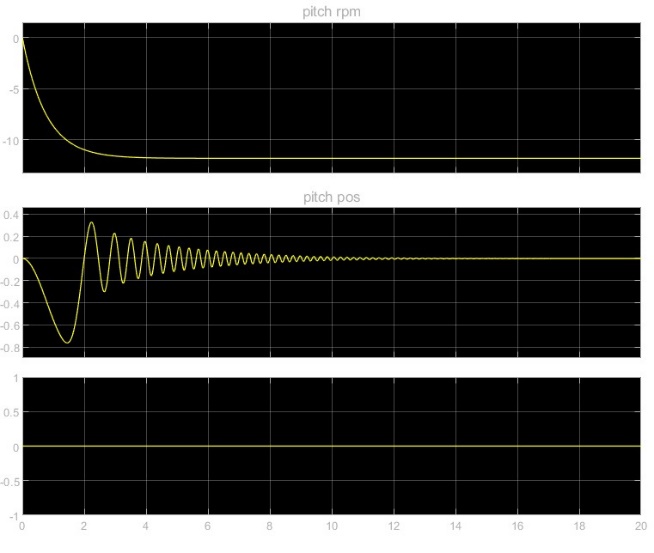
Pentru a identifica sistemul, am utilizat inițial modelul Simulink al echipamentului pentru a obține o precizie ridicată. Am descărcat graficele ieșirilor celor două elice, aplicând o comandă de 1 pe azimut și 0 pe pitch. Ulterior, am inversat intrările pentru a observa și celelalte două ieșiri din sistemul MIMO. Toate ieșirile s-au comportat conform unui sistem de ordinul întâi , astfel că am utilizat metoda () pentru a determina constanta de timp și

pentru a calcula constanta de proporționalitate a sistemului. După identificarea inițială pe model, am preluat datele de la motoare pentru a valida precizia identificării. Modelele obținute nu se suprapuneau perfect, așa că le-am ajustat pentru a obține o suprapunere adecvată.

A diagram of a computer

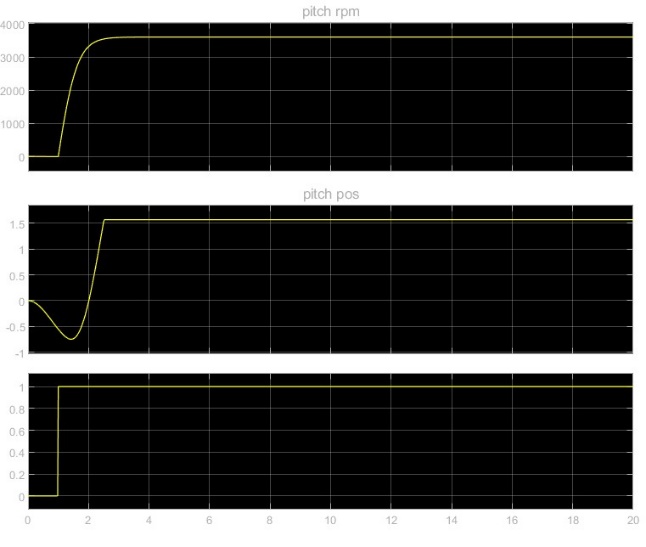
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Figură 1. Modelul Simulink al sistemului

A graph of a graph

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Figură 2. Iesirile pe Pitch la treaptă 0 Figură 3. Iesirile pe Azimuth la treaptă 1

A graph of a graph with a line

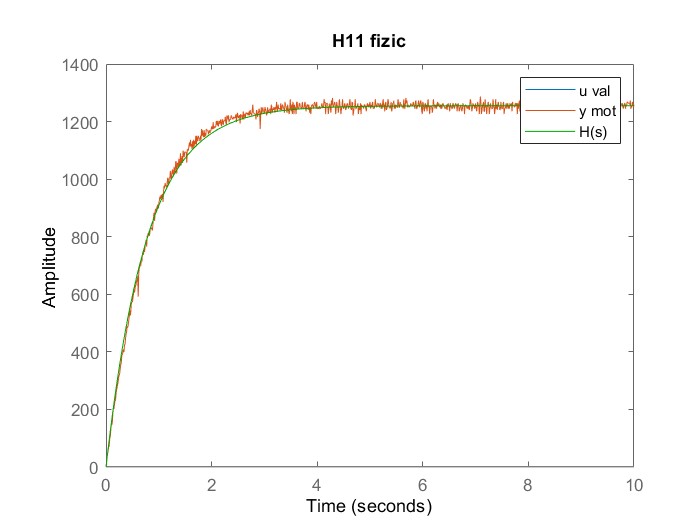
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Figură 4. Ieșirea pe Pitch la treapta 1 Figură 5. Ieșirea pe Azimuth la treapta 0

A graph of a number of objects

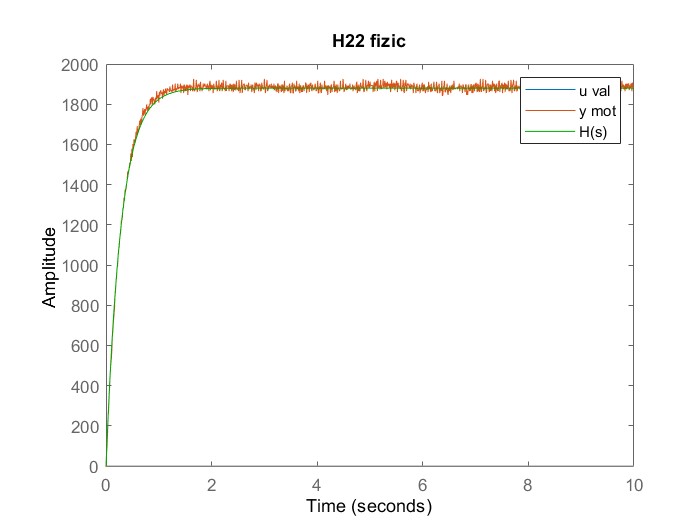
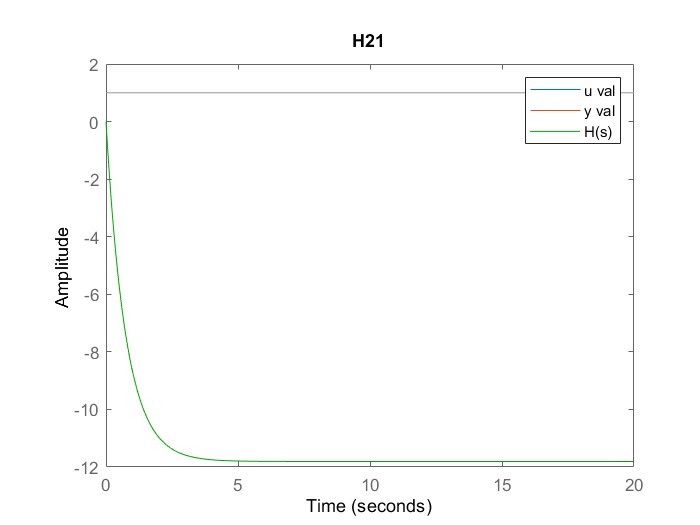
Description automatically generated with medium confidenceA graph of a graph showing a line

Description automatically generated with medium confidenceFigură 6. Tensiunea pe motorul Azimuth la treapt Figură 7. Tensiunea pe motorul Pitch la treapta 0.2

A graph of a number of objects

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Figură 8. Suprapunere identificare pe Pitch cu treapta Figură 9. Suprapunere identificare Pitch fără treapta

 Figură 10. Suprapunere identificare pe Azimuth cu treapta Figură 11. Suprapunere identificare Azimuth fără treapta

# Proiectarea sistemului de control

Având în vedere natura sa MIMO, am adoptat metoda de decuplare în favoarea descentralizării, întrucât aceasta conferă sistemului o mai mare robustețe. În cadrul acestei metode, obținem matricea de decuplare (D) și matricea proceselor (H), pe baza cărora sunt calculate regulatoarele. Am optat pentru metoda Gullemin-Truxel pentru calculul acestor regulatoare. Deși în mod obișnuit se impune ca sistemul în buclă închisă să fie un sistem de ordinul II, am decis să mențin sistemul ca fiind de ordinul I. Această decizie a fost luată având în vedere că matricea G conține doar sisteme de ordinul I, dorind să nu compromitem performanțele deja existente.

Am utilizat MATLAB pentru a implementa metoda de decuplare, obținând matricele D și H care descriu interacțiunile sistemului. Am impus matricei H să aibă elemente doar pe diagonala principală, reflectând absența interacțiunilor între variabilele de ieșire. Utilizând matricea H, am calculat matricea D, care determină acțiunea de decuplare necesară pentru a elimina interacțiunile dintre variabilele de ieșire.

În etapa următoare, am procedat la proiectarea regulatoarelor cu un timp de răspuns de cel puțin de două ori mai mic decât cel al sistemului, pentru a asigura o performanță adecvată a sistemului de control. Calculând regulatoarele, am obținut două controlere de tip PI (Proporțional-Integral) care urmează să fie conectate la blocurile de decuplare, asigurând astfel o reglare eficientă a sistemului twin rotor.

# Implementarea sistemului de control

Am început prin implementarea regulatoarelor PI și decuplatoarelor în schema de simulare a sistemului twin rotor în Simulink. Această etapă a permis verificarea inițială a performanțelor teoretice ale sistemului de control. După validarea simulării, regulatoarele au fost testate pe sistemul real pentru a evalua diferențele dintre modelul simulat și comportamentul fizic al sistemului. Această etapă a fost esențială pentru identificarea și corectarea eventualelor discrepanțe și pentru ajustarea fină a parametrilor regulatoarelor.

Aplicația oferă o interfață grafică intuitivă care permite monitorizarea în timp real a evoluției semnalelor de ieșire ale sistemului twin rotor. Aceasta facilitează analiza comportamentului dinamic al sistemului și evaluarea performanțelor regulatoarelor implementate. Interfața grafică permite utilizatorului să modifice schema Simulink înainte de a o rula pe motoare. Această funcționalitate este crucială pentru experimentarea și optimizarea diferitelor configurații de control. Aplicația convertește fișierul Simulink într-un cod executabil interpretabil de sistemul real. Această conversie asigură compatibilitatea și permite implementarea rapidă a modificărilor în mediul fizic.

A close-up of a blueprint

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Figură 12. Schema de simulare a sistemului de reglare

![A diagram of a machine

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UUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQB/9k=)

Figură 13. Sistemul implementat cu regulatoarele pe sistemul fizic

# Testare și analiza rezultate

La rularea modelului simulat, am constatat că regulatorul producea impulsuri ciudate și neașteptate. Aceste impulsuri erau neregulate și nu corespundeau cu răspunsul dorit al sistemului. Am analizat răspunsul sistemului în detaliu și am investigat posibilele cauze ale acestor impulsuri neregulate, concentrându-mă pe configurarea parametrilor regulatoarelor PI. La testarea pe sistemul real, am observat că motoarele nu se roteau suficient, ci doar câteva grade. Acest comportament sugera o problemă în implementarea regulatoarelor sau în configurarea sistemului de control. Am revenit la modelul din simulator pentru a analiza în detaliu configurația sistemului și a identificat eventualele erori de configurare. În special, am revizuit configurarea reacțiilor negative în cadrul schemei de control. După ajustarea reacțiilor negative, sistemul simulat s-a comportat conform așteptărilor și proiectării inițiale. Impulsurile ciudate au dispărut, iar răspunsul sistemului a devenit regulat și previzibil.

A graph of a function

Description automatically generated with medium confidence

Figură 14. Semnalele de iesire din regulator

A yellow lines on a black background

Description automatically generated

Figură 15. Semnale de intrare in simulator

A graph of a graph of a graph

Description automatically generated with medium confidence

Figură 16. Semnalele de iesire pentru pitch

A close-up of a graph

Description automatically generated

Figură 17. Semnale de iesire pentru azimuth

A graph of a graph

Description automatically generated with medium confidence**A graph of a graph with a line

Description automatically generated with medium confidence**

Figură 18. Iesire azimuth dupa schimbare Figură 19. Iesire pitch dupa schimbare

# Concluzii

Primul obiectiv pe care l-am îndeplinit era determinarea modelului matematic al sistemului twin rotor în simulator, sub forma de matrice de transfer. Am identificat funcțiile de transfer aplicând o tensiune pe motor și măsurând viteza de rotație rezultată. Am constatat funcțiile de transfer obținute au fost de ordinul I, ceea ce simplifică analiza și controlul sistemului.

Al doilea obiectiv era validarea modelului matematic identificat anterior. Am aplicat semnale treaptă de amplitudine mică pentru a preveni deteriorarea motoarelor și am comparat răspunsurile obținute cu modelul simulat. Au fost observate diferențe între modelul teoretic și comportamentul real al sistemului, care au fost corectate pentru a asigura o corespondență mai bună.

Al treilea obiectiv era aplicarea metodei de decuplare pentru a reduce interacțiunile între intrările și ieșirile sistemului. Am urmat cu atenție pașii necesari pentru a implementa corect decuplarea și pentru a evita erorile în configurarea matricelor de decuplare. Implementarea decuplării a fost realizată cu succes în simulator, asigurând un control mai robust și precis.

Al patrulea obiectiv era calcularea regulatoarelor folosind metoda Gullemin-Truxel. Am aplicat metoda Gullemin-Truxel, stabilind ca sistemul în buclă închisă să fie de ordinul I pentru a menține performanțele obținute anterior. Regulatoarele calculate au demonstrat performanțe bune în simulările preliminare, indicând o implementare teoretic corectă.

Ultimul obiectiv era Testarea și implementarea structurii de control pe sistemul real. Am testat sistemul pe hardware-ul real și am observat că motoarele nu se roteau suficient, indicând o problemă în implementarea inițială. Problemele au fost identificate ca fiind legate de configurarea reacțiilor negative în schema Simulink. Din păcate, ajustările necesare au fost identificate prea târziu pentru a fi implementate și testate complet pe sistemul real.

Proiectul a parcurs toate etapele necesare pentru dezvoltarea și implementarea unui sistem de control pentru sistemul twin rotor, de la identificarea modelului matematic până la testarea pe hardware-ul real. Deși implementarea finală a întâmpinat dificultăți neașteptate, proiectul a oferit o înțelegere aprofundată a metodologiilor de control și a provocărilor asociate sistemelor MIMO.