ÉCOLE POLYTECHNIQUE
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Thymio Road Network

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Contents

1 Introduction

Le Thymio est un petit robot utilisé pour l'éducation et le fun. C'est un robot abordable et robuste conçu pour supporter une utilisation difficile.
Dans ce projet, nous voulons creer un réseau de transport dans lequel une quarantaine de robots pourraient se déplacer librement d'un endroit à un autre.

Pour le réaliser nous allons devoir construire et assembler toutes les parties nécéssaires à un reséeau routier adapté au format du Thymio.

Le Thymio possède de base de nombreux capteurs qui seront presque suffisants pour realiser un système efficient et varié. Les capacité compatationnelles seront elles utilisées au maximum de leurs capacités.

En raison de la quantité de travail, le projet a été divisé en deux parties, la première, la partie locale se concentre sur le comportement bas-niveau des robots. La deuxième, la partie globale comporte tous les developpements relatifs au système complets

Plan

The project is organized as follow. In the first section, I present the goals and the tools useful for the whole project and more precisely on the global part. After, the report is structured in the chronological order including for each section an introduction that makes the links with the project's objectives. In the **Section 3**, I describe the reflexion and the choices relative of the minimal design of the network and the vital component for the Thymios. In **Section 4**, I present the main complexification of the fonctionnalities mandatory for the high-level work. **Section 5**, Explain the theory and the technical control used to optimise the system. And in the **Section 6**, the result of the test and the analysis will be done. The last **Section** contains the conclusion.

2 Description of the projet

2.1 Thymio Robot

The Thymio is an educational robot developed at the EPFL. Numerous sensors and actuators, as well as a graphical and textual programming interfaces allow to develop many applications. Amongst these sensors we can find buttons, many proximity sensors, a 3-axis accelerometers, a temperature sensor and a microphone (with intensity detection). And as actuators we have, 2 motors (used for differential drive), many LEDs and a speaker [1].

2.2 Aseba Studio

To program the robot, we used the text interface Aseba Studio. A visual programming interface exists as well but it is mainly used for programming initiation purposes because of its restricitons. The Aseba language is event-based, which means that a portion of the code is executed only when a certain event occurs. All the sensors are provoking events at regular frequencies, but we can create event as well to trigger a certain behavior.[1].

2.3 Microcontroler capabilities

The microcontroller is a blablabla, Its capalbilities are limited. The main problem are the maximum number of variable (around 600) and the bytecode size (around 1500).

2.4 Goal and division of the project

The Goal of this project is to create all the infrastructure and the software to make a road network for around fourty thymios. It will be inspired by real road and transportation network. The network will be printed on a giant poster and it need to contains roads, intersections, and parkings.

The "car"' thymios must be able to circule freely anywhere in the map, in a fluid flow and with respect to the rules of the network.

To achieve that, the project were divide in two part. The local part is done by Loïc Dubois and the global part by me.

- **Local part**: Focus on the Thymios movement in the network
  - **Line following and barcode scanning**
  - **Obstacle and collision avoidance**
  - **Design intersection with the second part of the project**
  - **Control at intersection**
- **Global part**: Concentrate on the system as a whole
  - **Fluid flow in the city**
  - **Design intersection with the first part of the project**
  - **Manage interaction**
  - **High-level decision**

2.5 Description of the goals

Here I describe precisely the different objectives of the project.

local part

Done in the project of **Loïc**

Line following and barcode scanning

Design of method the robots use to stay on the road (barcode + lane markings + controller) Barcode scanning at different speeds

Obstacle and collision avoidance

Obstacle/collision avoidance between the robots

Design intersection with the second part of the project

Design of intersections (in collaboration with the student building the global infrastructure). The choice of an appropriate intersection method should be made (crossroad, roundabout, tracks lights, trc barrier, etc.). The expected advantages and disadvantages of all options should be weighed, and one option should be carefully selected.

Control at intersection

Control at intersections. Given a choice of path, the robot should be able to execute that choice (e.g., turning left, taking an exit, changing lanes, etc.).

Global part

Design of the city

I should consider how to achieve fluid flow of the robots in the city. It will include a certain list of special places (train station, police building...). It should include diferent sorts of lanes (slow, fast, ...) This objective is discussed in the **Section 3** and is done with **Loic**

Design of the intersections

The choice of an appropriate intersection method should be made (crossroad, roundabout, trac lights, trac barrier, etc.). The expected advantages and disadvantages of all options should be weighed, and one option should be carefully selected. This objective is described in the **Section 3** and in the **Section 5** and is done with **Loic**

Manage Interaction

The robots should be able to follow the rules of the intersections and avoid collisions. This goal is started in the **section 3** ans finish in the **Section 5**

High level decision

To allow Thymios to decide which pathways to take, the student should explore at least two diferent strategies (random, path planning (point A to B, prediffined route, coordination ?) He should analyze these strategies and discuss them. This objective is discussed in the **Section 5**

Coordinated decision

Develop a coordinated joint control strategy for the Thymios, by which they can cooperate to make the network more efficient (could be done in collaboration with the other student). This objective is done in the **Section 5**

Internal Map representation

Implement an internal map representation for one or more Thymios to use for more advanced decision-making. This objective is described in the **Section 4**

3 Design choice

In this section, I describe the reflexion and the discusion that have lead to the choice of our final design of the city. All this where made with Loïc. The base of this work was, with a minimum functionnal design, we can make, test and debug any complexification. In order to achieve this "minimal design" we have done all these objectives:
Design of the city
Intersection mandgement(most simple)
Interaction(most simple)

3.1 Fonctionnality mandatory

To make a transportation network, the robots must have th capacity to follow a complex way with its integrated captors. It must be free to visit any points of the map and the whole group of thymio need to drive in the same time without blockage.

We wanted also to have simple interaction only based on the proximity sensor(without any communication or coordination) and an intersection working with this.

we have choose the train model with round-about intersection

Train model

- **One-way line**
- **Continues lines**
- **Railway track point with preprogrammed behavior in the area without guidance**

Round-about

- **One-way turn**
- **if correctly design less chance of blockage**
- **If lost, going out with the next exit**

3.2 Way type

The network is composed by numerous of straight lines and turns. To navigate in the network, the Thymio should be able to follow these lines and search for some if it is lost. We can compare different possibiliies in the table 1 (solutions illustrated in figure 4).

Table 1: Possible line designs

Method	Pros	Cons
thick Black line	Default line following technique	use 2 captors for working
Gradient	Use of one captors and precise follow	Depending on the printer
White Line Between two Black lines	Simple No loss of the road	Use two sensors to know position No control between the lines

Our choice wher going on the gradient line (like in the light painting project) because, we can use the second captor for the scan of the environnment.

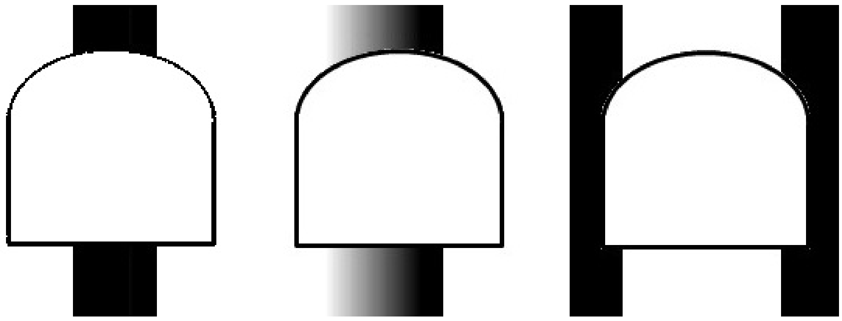

Figure 1: Different possible line designs associated with table 1

3.3 Information the environnement

The thymio has many infrared captors, two in direction of the floor and many horizontal to detect the osbtacle. These captors can also be used to communicate withe others thymios. But we don't have the direction of this communication so the location is not garanted.

So for this kind of information, we have decided to use some barcode. This information is totaly tie in it location.

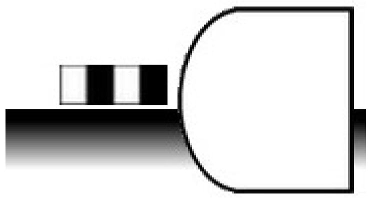

Figure 2: Barcode scanning

Lo¨c has made the test and decided to use 3 bit barcode becaus of the fiability. the drawback of this limitation is that the 8 posibilites don't give the hoped amount of information, so i need to increase the complexity to overcome this problem

3.4 Intersection management

For the choice of intersection.

The choice of intersections was done with Loïc who was also working on the project.

Table 2: Possible intersections

Intersection	**Pros**	**Cons**
Branching	Simple Smooth and continuous	Limited to 2 different ways Must cross a line
Roundabout	Generalization of branching	big size
Cross road	Small size	Need control
Cross road	3 possible ways	Must move without line following

In this section, we want inerstion base on the proximity sensors and without coordination to keep the design simple. So we have choose the branching and the round-about for the intersections. Intersection : Round-about

- **Captors placement**:

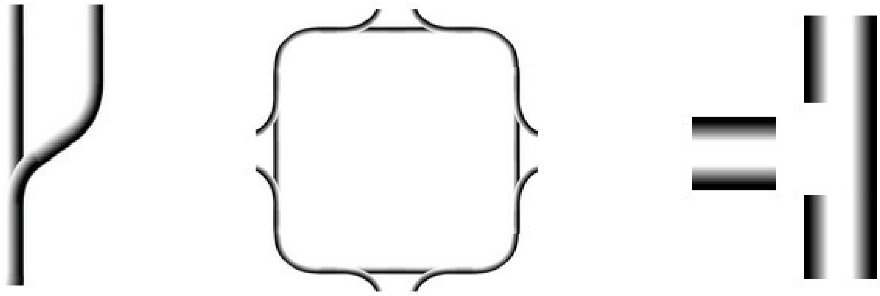

Figure 3: Illustration of different possible intersections

- **Half-way possibilities**:
- **Without control**:

Parking : Branching

- **Simple one direction track**:
- **Can rest without stop all the others thymio**:
- **Robust**:

3.5 Design de la map minimal

Contient deux location et un rond point There is the minimal map.She have 3 nodes, 2 parking in

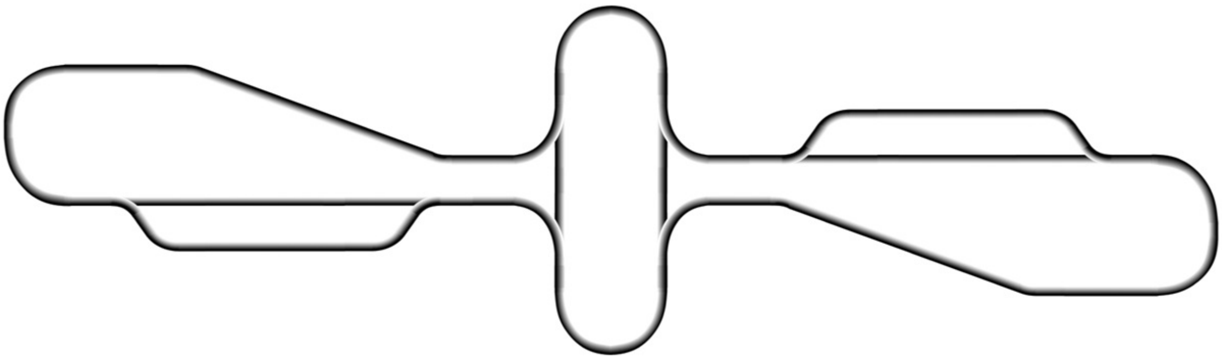

Figure 4: Carte 1

the extremity and one intersection, the center.

3.6 Test and result

On this map, we have put 15 thymios in random mode and with the leds showing the state of the robots. See video in annexe. Observation: High density in the center of the map Probleme with the parking branch design Some minor problem of collision in barcode lecture (fixed)

3.7 Conclusion of section 3

With this map, we have test 15 thymios in the same time and understand the limit of this design. After that we can understand and do the complexification needed for the others goal.

4 Complexification and improvement

In this part, I describe the main improvement programmed for the behavior of th thymios. It is the internal map and the communication interthymios. These two complexification where urge because in addition that the map is an additional goal, they allow the realisation of multiple main objectives by compensate the limitation of the captors.

They will be useful for these goals:

- **Manage interaction in the intersection**:
- **High-level decision**:

4.1 How to manage interaction and take high level decision

Before this section, the intersection are managed only by the proximity captors. This simple behavior can introduce blckage in some particular situation, eg if two thymio ar detecting each other simultaneously and block in a round-about.

To improve the management of the intersections, we have identified two possibilities:

- **Coordination inter-thymio**: Use of the communication to decide some priority (like nomral carrefour)
- **Specialised thymio**: To have some thymio how controle the the traffic in the lane (Signal thymio)

The signal thymios are simple to make and are less limited in ressources (memory and power) because the don't need to mange their movement. And the probleme with coordination is the size of the communication and the need to exchange many information before any decision could taken.

High level When the control of intersection possible, the high -level decision need possibilities of measurement to modifiy the decisions in real-time

4.2 Raisons du développement de la carte interne

Le fait que les bar code se limite a 3 bit et que la communication infrarouge correspond a du broadcast (avec quelques limitation) impose la representation interne de la carte a tous les thymio voitures. En effet du au fait que le seul moyen de communication de thymio (actuellement) est les capteurs infrarouge, et que la zone de reception comme celle de transmission couvre plus de 180 degrés. (voir la figure 5)

Il en resulterait beaucoup d'erreur potentiel de transmission car les thymio ne pourraient pascomprendre que les message correspond a la branche sur laquelle ils se trouvent. Même si la distance max de transmission est de 40 cm.

Il en resulte que les thymios on besoins de savoir où ils se trouvent pour comprendre qu'un ordre leur est addressé.

Une autre possibilité aurait été de nommer tous les thymio et d'avoir un ordinateur qui analyse le reseau a l'aide d'une caméra et broadcast les ordres avec le nom des thymios en sus.

Après reflexion, je suis parti sur la reprensentation interne de la map car elle permet un fonctionnement decentralisé du système ainsi que de la centraliser plus tard. elle ferme donc moins de portes pour la suite du projet.

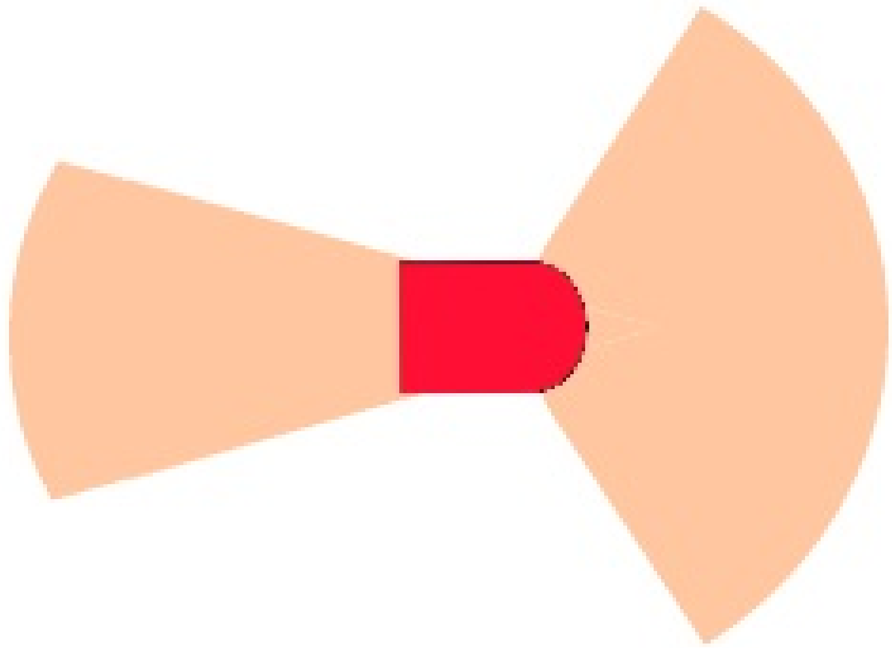

Figure 5: Zone de reception et de transmission d'un thymio

4.3 la map interne

La carte interne doit permettre a chaque thymio de connaitre sa position a tout moment. Elle doit etre intégrable malgre les ressources limitées du robots.

- **Permet au robot de connaître sa position**
- **Mis à jour à chaque déplacement**
- **Minimum de**
- **Besoin de correction d'erreur**
- **Utile pour réaliser la plupart des objectifs du projet**

Realisation

Puissance de calcul et mémoire limitée o Plan représenté avec un graph non-orienté map[0]=0b10010 o Utilisation de mémoire par paliers de 14 noeuds (2 bit pour le type de noeud) Un deuxième tableau stocke l'ordre des sorties des intersections orientedIntersection[0]=0b010001 o Maximum 5 entrées-sorties par intersections. o Utilisation de mémoire

Le Thymio est capable de connaitre à tout moment sa position, si sa position de départ est connue et qu'il ne fait pas d'erreurs de lecture.

4.4 Communication interthymio

Une fois que la carte interne a été developpée, les thymio pour voit comprendre quand les ordres leurs sont addressé.

La communication de base des thymio se déroule surtout dnas un seul sens, du thymio signal aux thymio voitures. Foncierement, le thymio signal indique a tout moment quel sont les routes ouvertes et fermées.

Commucation

The communication use the proximity infrared sensors. elle transmet jusqua 11bit de données par 100[ms] his limit is 40 cm .

Le but du robts signal est de transmettre l'état de toutes les routes qu'il contrôle le olus vite possible J'ai donc implémenté ce petit protocole de disque de broadcast ave une prériode diffusion de 200[ms].

La precedente position + 1000 = vert La precedente position + 2000 = rouge

Le thymio peuvent donc comporendre directement ces informations et réagoir fonction très rapidement.

- **Permet au robot de connaître sa position**
- **Mis à jour à chaque déplacement**
- **Minimum de**
- **Besoin de correction d'erreur**
- **Utile pour réaliser la plupart des objectifs du projet**

Mesures

Des qu'un thymio voiture recoit une nouvelle information, il répond par un jeton de présence. Ce qui engage le mode de communication des voiture.

Elle va donner toute ses informations (avec un système d'ettente de réponse) et lancer le derniuer mode de communication, le ping.

Le ping est transmis au autres voitures et permet de mesurer combien de voiture sont derrière sur la meme route.

Possibilités et limites

Limite du ping :

Probleme de ne pas transmettre les infos aux autre routes. Ne pas compté plus d'une fois chaque thymio voiture sur la route.

Choix Geo cast et broadcast partiel

Implementation

Conclusion

5 Controle et mesures du système

Dans cette section je vais décrire les differante modélisations et technique de controle utilisée lors de ce porjet. Ces differantes techniques de controle et de mesure servent a realiser differants objectifs du projet et permette de comparer le système a un réseau routier physique.

5.1 Théorie et modélisation de réseaux routier

La traffic routier se mesure et modélise de plusieurs facons, je vais ici décrir les mesures et modèle simple represeant les phénomène les plus caractéristiques d'un réseau routier.

Deux approches existent, la macroscopiqie et la microscopique se focalisant sur les vehicules eux-même. je ne vais décrir que l'approche macro vu qu'elle est suffisante pour comprendre les differantes technique d'optimisations et de controle presentées ci-après.

Variables

Trois variables principales

- **Density**:
$$x + y + z = 4$$
- **Flow**
- **Speed**

Avec ces trois variables, nous pouvons utiliser les modèl de bas de premier ordre :

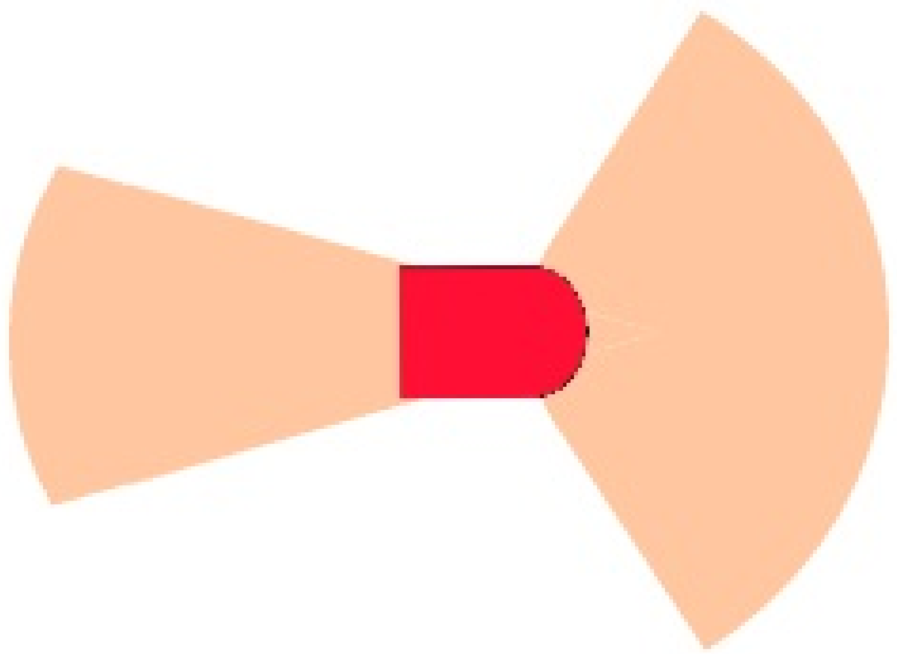

Figure 6: Modèle de premier ordre (grrenfiel avec des données reel d'un réseau routier)

Les valeurs correspondant de ces modèle, sont calculeé a l'aide d'un régression linéaire sur des données réel.

Elle nous permette de voir si notre reseau se comportera comme un reseau reel. Cf section tests et mesures

5.2 Pourquoi et comment

Lister les différantes possibilités imaginées A partir de la nous pouvons realiser et tester en condition reel notre reseau pour voir commen il se comporte. Ensuit jai implementer les robots signaux pour gerer correctement les intersections et pouvoir tester différantes techniques de controle

5.3 Utilisation des robots signaux

Les robots signaux seront pla

Placement

Ils sont placés l'un sur l l'autre pour avoir une diffusion correcte de leurs informations. En effet, a pres avoir teste differantes placements, la dimession minimal des thymios et la distance de transmission ne laissait aucun autre choix. Grace aux travaux de Blu blu, jai acces a des thymio wifi qui me permette de mettre deux thymio de controle pour chaque carrefour.

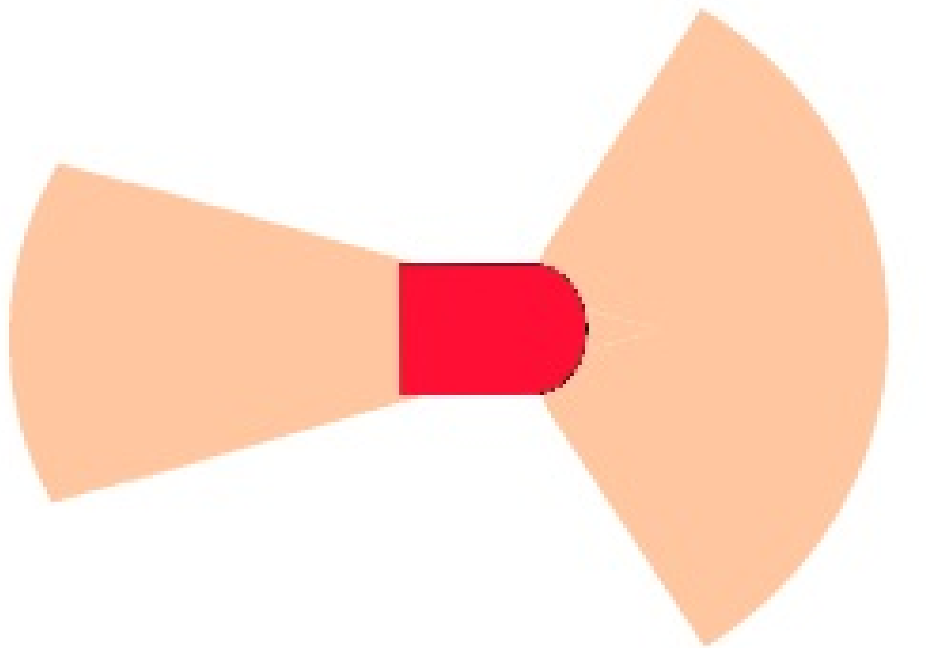

Figure 7: Placement des thymios signaux

Mesures

Les thymio signaux utilisent les deux complexification decrites dans la section precedantes et integre de plus un stockage des différant thymio.

pour pouvoir mesuré la densité en temps réel, j'ai implémenté un système de ping permettant de mesurer le nombre de thymio présent au feu. Cette mesure est utile a tous lea algorithm adaptatif presenté ci apres.

Explique le principes de transmission de l'information

Controle

Dans ces carrefour et dans un soucis de simplification , je vais considéré une seule ligne ouverte par phase du carrefour. Cette technique Ouverture et fermeture de ligne

5.4 Programmation et implementation

Types d'algorythmes utilisables

Type d'algorythmes imaginé 1. algo de base en feu circulaire 2. Algo s'améliorant en fonction de la densité 3 ALgo plus rigoureux, basé sur une MDP 4 amélioration intuitive de la MDP

Gestion en feu de croisements

Algo s'améliorant en fonction de la densité

ALgo plus rigoureux, basé sur une MDP

v

amélioration intuitive de la MDP

v

6 Tests and measure

7 Conclusion

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SEMESTER PROJECT — SPRING 2014–2015			
Title:	Thymio Traffic Network - Global Infrastructure		
Student:	Benjamin Kern	**Section:**	Électrique/Électronique
Professor:	Francesco Mondada		
Assistant 1:	Stefan Witwicki	**Assistant 2:**	Christophe Barraud

Project Statement

Context. Thymio is a small mobile robot developed here at EPFL for education and for fun. It has two wheels, 9 infrared sensors, an accelerometer, a microphone, speakers, and 39 brightly-colored LEDs. Imagine a community of Thymios coexisting in an urban environment. Each Thymio has a purpose ; and with that purpose, things to do and places to go. Here, our motivation is to build up a a transportation infrastructure for the Thymio society in the form of a road network.

The road network will be realized in two parts : *local* infrastructure for a Thymio's movement with the network, and *global* infrastructure, for the functioning of the network as a whole. This project is focused on the latter part, though will be performed in close collaboration with other half of the project.

Core Objectives.
- Design of a city. The student should consider how to achieve fluid flow of traffic of the robots. The city should include a certain list of special places (train station, police building...). It should include different sorts of lanes (slow, fast, one-way, two-way, etc.)
- Design of intersections (in collaboration with the student building the *local infrastructure*). The choice of an appropriate intersection method should be made (crossroad, roundabout, traffic lights, traffic barrier, etc.). The expected advantages and disadvantages of all options should be weighed, and one option should be carefully selected.
- Manage interactions in an intersection. The robots should be able to follow the rules of the intersections and avoid collisions.
- High-level decision making strategies. To allow Thymios to decide which pathways to take, the student should explore at least two different strategies (random, path planning (point A to B), predefined route, coordination ?) He should analyze these strategies and discuss them.

Additional Objectives. The following constitute additional goals whose treatment can each significantly increase the contribution of the project *assuming* the core objectives have already been fulfilled to a reasonable degree of satisfaction.

- Develop a coordinated joint control strategy for the Thymios, by which they can cooperate to make the network more efficient (could be done in collaboration with the other student).
- Implement an internal map representation for one or more Thymios to use for more advanced decision-making.
- Create high priority vehicles (police car, ambulance, street cleaner...) and make them have the priority on regular robots (could be done in collaboration with the other student).
- Your own creative ideas (to be discussed with the project assistants).

Bibliography

[1] Thymio. https://aseba.wikidot.com/, April 2015.