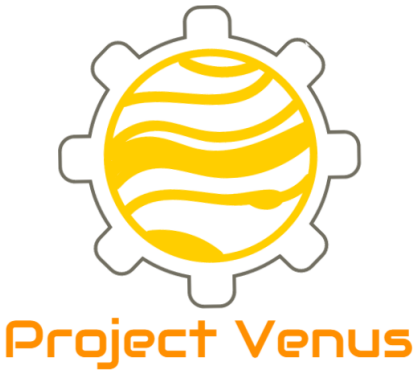


Technical Specification

SDP Group 15-H

Emilia Bogdanova
Patrick Green
Julijonas Kikutis
David McArthur
Aseem Narang
Ankit Sonkar

The University of Edinburgh

Contents

1 System architecture

The oldest system called the Milestone Venus had a simple structure as seen in Figure 1. Commands were complete once a predefined rotary value was obtained. This was used to calibrate the four motions and did not stretch the capabilities of the robot.

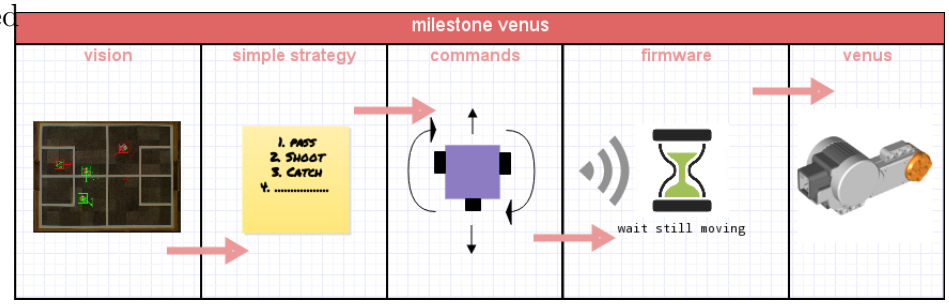


Figure 1: The architecture of Milestone Venus

The updated system in Figure 2 used the value of a potential field obtained by summing up the contributions of all obstacles in the pitch each having a particular type of a field. The robot was modelled as an automaton in a finite grid with each square having its own potential. Using calibrated swerving motions from square to square the pitch could be navigated intelligently.

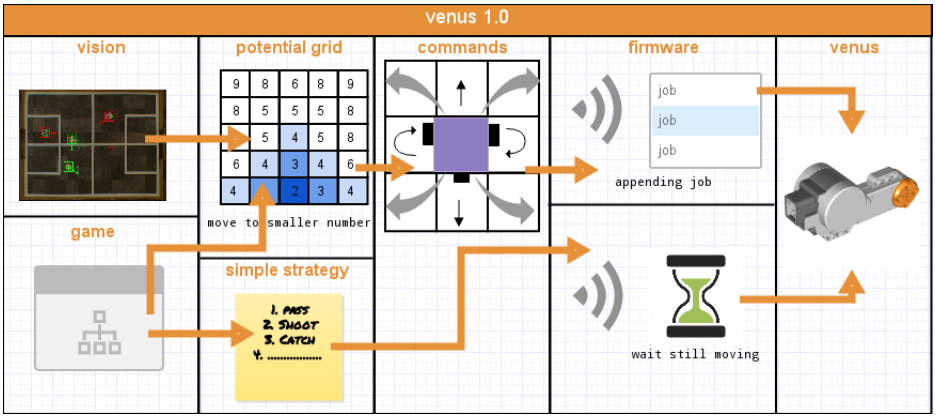


Figure 2: The architecture of Venus 1.0

Navigational motions were added to a job list on the Arduino. This ensured that the motion was continuous and not affected by lag. The high level planning was implemented by a state machine that controlled the on/off switches for each obstacles field and various addition fields imitating behaviours such as intercept and grab ball. These addition fields worked for all possible situations in the game unlike the method built for the Milestone Venus. The potential fields could be compounded together into states without difficulties, making high level planning easier to test and modular unlike the set of commands built in the Milestone Venus.

For the final system in Figure 3 the first large change was to the robot itself which was redesigned to be four wheel holonomic. After re-calibrations with encoders simple motions like kicking and grabbing were implemented using the original system that

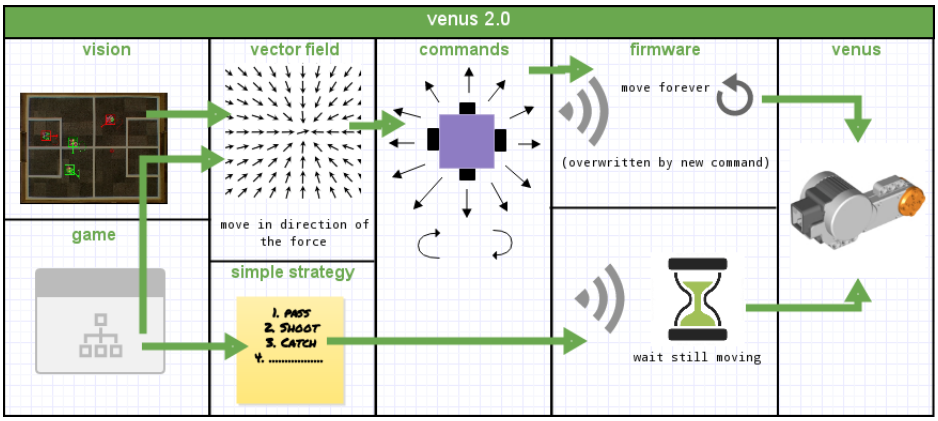


Figure 3: The system architecture of Venus 2.0

waits until the first
motion has stopped. On top of this, the move forever method was added to the firmware, which meant that movements as granular as the latency of the communications system could be achieved. Using this, a planner was built that provided the movement trajectories of the robot to be calculated straight from a vector field created from our potential fields in the previous design. This not only made the robot faster but it meant that it could deal with more complicated mazes of potentials not capable by the Venus 1.0 as previously it could not change direction sharp enough. Also, although the move forever function relied solely on the vision, it still proved more precise than the job scheduling from the previous design as the old robot would often move out of alignment with the grid to which its motions were confined. Moreover, the final system relaxed the undistortion of the vision feed to increase the reaction speed of the robot. By removing its lag it was able to keep up more accurately with the pace of the game.

2 Hardware components

2.1 Chassis structure

To obtain more constant torque both designs used the nxt motors for movement. However as the rear wheel in version 1.0 was not powerful enough to swerve the robots orientation with enough granularity, the robot chassis was rethought.

The final design uses a four wheeled holonomic base instead of our three wheeled one. It enabled fast motion in any direction meaning the robot could respond quickly to a change in play. Using vector fields a given direction could be implemented instantly. The motion was constructed by calculating the angle between the desired direction and the robot orientation x. This was used to compute the driving components that were sent to the Arduino as seen in Figure 4. The matrix multiplication below was used to extract the driving powers and then each power was scaled up by a factor of 100 divided by the absolute maximum of the four motor powers.

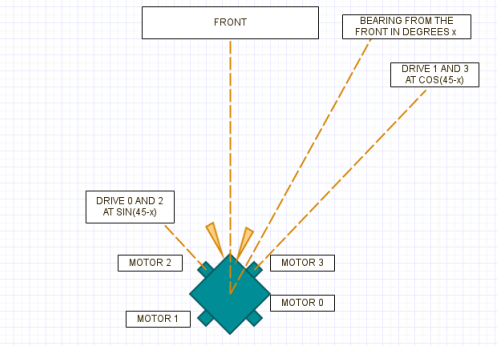


Figure 4: Visualisation of the calculating the motor power components

$$\begin{pmatrix} \text{MOTOR 0} \\ \text{MOTOR 1} \\ \text{MOTOR 2} \\ \text{MOTOR 3} \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ 0 & -1 \\ -1 & 0 \\ 0 & 1 \end{pmatrix} \begin{pmatrix} \cos(45 - x) \\ \sin(45 - x) \end{pmatrix}$$

2.2 Weight distribution

To simplify holonomic calculations, except for the grabber the final robot is completely symmetrical in two planes. The majority of the weight coming from the batteries and motors are placed directly in the middle for stability to evenly distribute the weight between each wheel. The previous design was a lot heavier towards the rear due to the amount of space

needed for the kicker causing different forward and backward motion calibrations. This prevented us from obtaining accurate swerving and led to us scraping the chassis structure for the current four wheeled design.

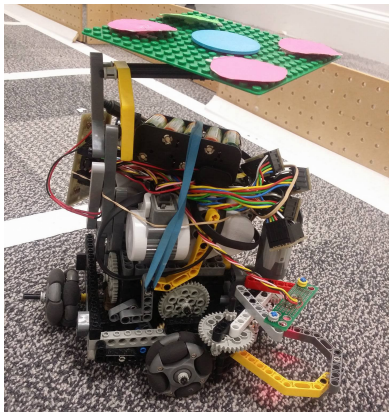


Figure 5: Venus 2.0

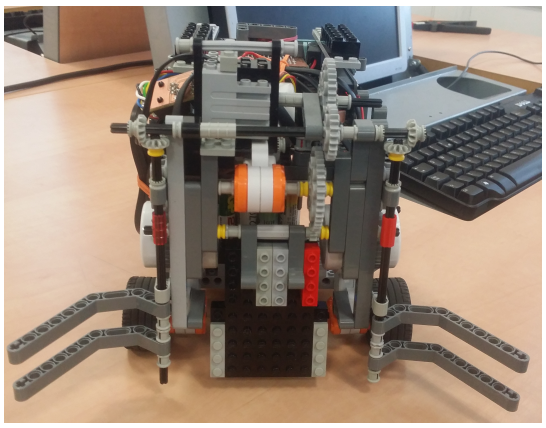


Figure 6: Venus 1.0

2.3 Grabber and kicker

The grabber consists of two symmetric parts placed one slightly above the other as seen in Figure 5. To keep the robot within dimensions the grabber arms overlap enabling a large span but still within regulations when closed. A symmetric gear system is used so that both arms are opened and closed at the same time. Unlike the original design shown in Figure 6, the arm axles were placed closer together so that the grabbed ball would always be in the same position increasing the reliability of the sensor and the kick.

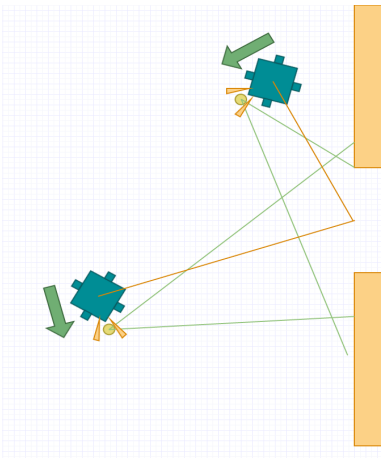


Figure 7: Correct kick rotation

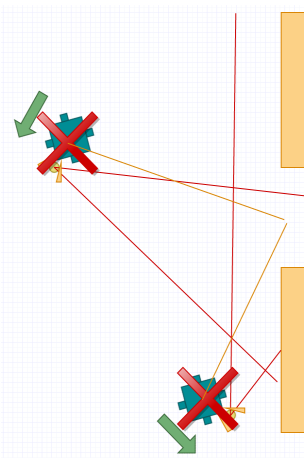


Figure 8: Incorrect kick rotation

The newest design does not have a kicker. Instead, the kick is made by turning the robot and opening the grabber at the same time. The main incentive of this design was to reduce the asymmetric weight distribution which would have been catastrophic in optimising the holonomic movement. The robot rotates in the intended kick direction when it is aligning itself with the goal. In doing this the centrifugal force holds the ball towards the end of the grabber and the ball is in contact with the claw that will apply the kicking force. This

increases the accuracy of the kick as the ball always starts in a similar position. As the error margin of the kick is asymmetric and biased towards undershooting, the kick is initiated in different directions in different positions on the pitch. The y dimension is split into four segments: 0, $\frac{1}{4}$, $\frac{1}{2}$, and $\frac{3}{4}$. In Figures 7 and 8 the robots demonstrate each segment and its correct and incorrect kick directions. This kicking mechanism is not only more powerful than the previous design but it is also able to confuse the defence strategies of opponents tournament[1].

3 Documentation of the code

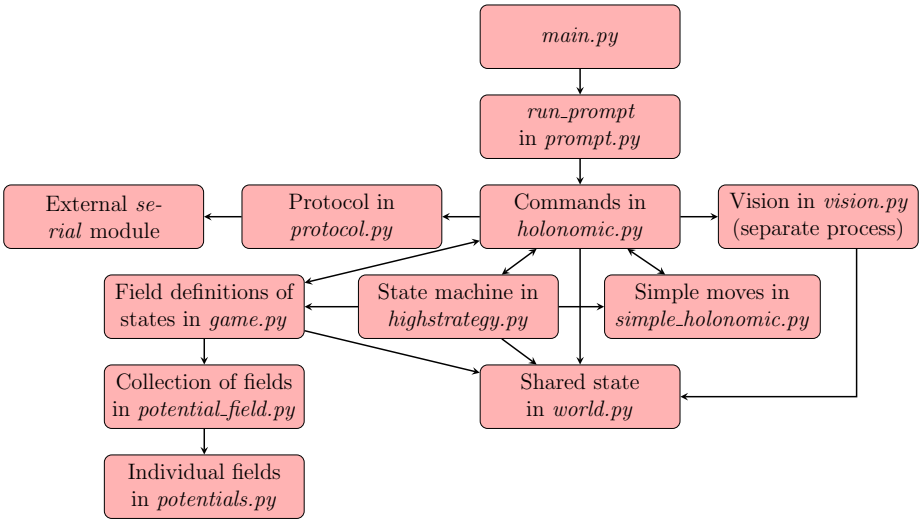


Figure 9: Dependency graph of Python modules in the system

The code is subdivided into several Python modules as seen in Figure 9. The module *main* is used to launch the *prompt* module. The commands in the prompt are provided by the *commands* module. It creates instances of protocol, vision, and state machine objects from the respective modules. The vision object is run on a separate thread to process frames asynchronously with constantly updated shared world state kept in a *World* object. At the same time the prompt is provided for the user. The command to run the strategy is called `hs`. This command constantly queries the state machine in the *highstrategy* module. The state machine checks the world state to decide which state it is currently in and then performs the associated action. It is done either by handing over the execution to *game* module to construct a potential field and perform the best action based on it or performing a predefined move from the *simple_holonomic* module.

All code except the color calibration user interface in the *vision* module is an original work. Libraries used are *pyserial*, *numpy*, *scipy*, and *OpenCV*.

3.1 Communications

The communication interface between the Arduino and PC is low level as the PC decides and specifies the individual motor numbers and rotary encoder value or time duration for

[1]Footage of one such example of a confusing spin kick is available at `https://youtu.be/VJLo2x2gdGk`.

which they will be powered. Then the Arduino sends acknowledgement to the PC about the arrival of the command, turns the motors on, and sets the specified timeouts to stop them. The messages are human-readable, newline-terminated and tokens inside them are separated by spaces. The specified motor power can be negative, in which case it means backwards direction. Each message which changes the state of the robot has a sequence number and checksum that are checked in the Arduino. The messages used in the protocol are listed in Table 1. The communication messages are constructed in the *Protocol* class using methods named after the corresponding message in `control/protocol.py` and these are used in the motion commands in `control/holonomic.py`.

Rotate the motors for $n$constructed a ms	`M seqNo checksum n motorNo power...`
Rotate the motors for n rotary values	`R seqNo checksum n motorNo power...`
Rotate the motors indefinitely	`V seqNo checksum motorNo power...`
Stop all motors	`S seqNo checksum`
Return `D` if all motors are stopped	`I`
Handshake, reset the sequence number	`H`
Query light sensor, return `D` or `N`	`A threshold`
Transfer a byte to I2C bus	`T byteInDecimalASCII`

Table 1: Messages available in the protocol

3.2 Arduino

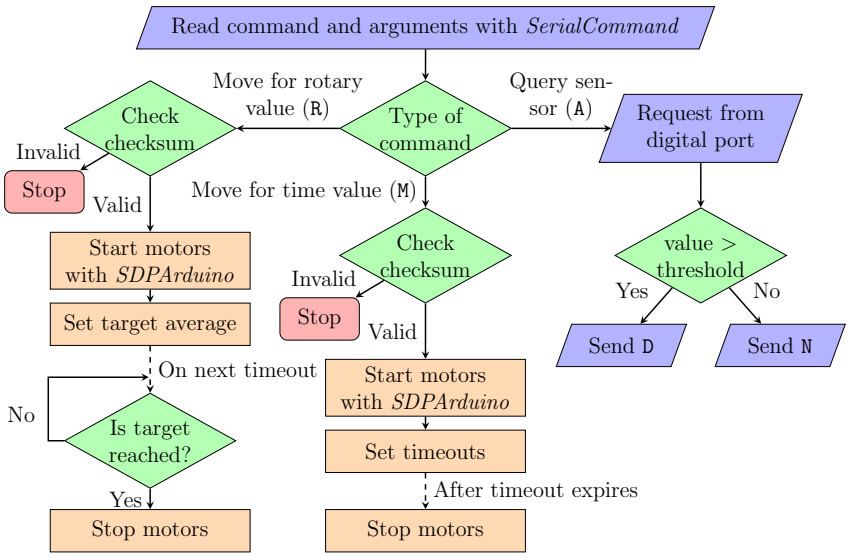


Figure 10: Flowchart of message processing in the Arduino

The Arduino code uses the *SerialCommand* library to buffer and tokenize the commands received over the serial link. Messages changing the world state are sent with a sequence number and checksum which is the sum of all the parameters following it. If the sequence number matches the one from the last command, acknowledgement is sent but no further work is performed for the duplicate message. This handles the situation arising when an acknowledgement from the Arduino does not reach the PC and and the PC generates a duplicate message. If the checksum does not match, the Arduino code ignores the message

and does not send an acknowledgement, thus forcing the PC to send the same message again.

If any of the motor move commands are sent, the motors are started immediately using the *SDPArduino* library. Then the Arduino schedules when to stop the motors and there are two methods to perform that: either a time value or rotary encoder value. The flowchart for these two methods, along with querying the light sensor, are detailed in Figure 10. In the case of the time value, a timeout is set to stop each single motor using *setTimeout* from the *SimpleTimer* library. In the case of rotary encoder value, *setInterval* is used which calls a function every 5 ms that queries the rotary encoder board and stops the motors when the average of all four motor rotary encoder values reaches the target value. These approaches using timers allows the robot to receive commands asynchronously, that is, a command is not blocking during its execution and the PC software could, for example, send another command simultaneously to engage the kicker while the robot is in motion. The Arduino message handling is located in `arduino/arduino.ino` file.

A buffer of upcoming motor jobs has also been implemented in the Arduino code to ensure continuous motion but it was deemed unnecessary as vision could issue new commands quickly enough without the robot coming to halt. The current implementation also never stops a motor when a new command arrives for the same motor, instead it just executes the new command, ensuring continuous motion.

4 Sensors

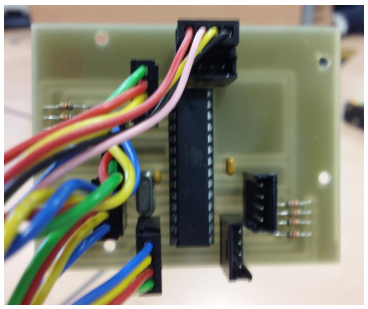


Figure 11: The rotary encoder board

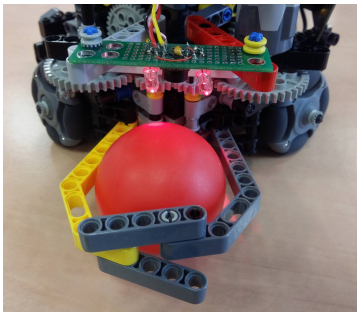


Figure 12: The light sensor with the ball

Rotary encoder board

The exact configuration of the encoder board is specified in the user guide. The decision behind using NXT motors as opposed to others was directly due to there encoders. We wanted to keep this function of controlling and stopping movement after specific numbers of rotary values because it worked well for us in our old design. For the grab ball task in particular it is essential that encoders are used as computing conversions between rotary values and cm meant we could deal with grabbing balls from corners and wall also.

Light Sensor

The light sensor functionality is explained in the user-guide and can be seen in Figure 12. Our decision of sensor was a downside to the robot and if built again it would be recommended that a more reliable one is used.

4.1 Vision

In order to detect the robots and ball the following steps are executed:

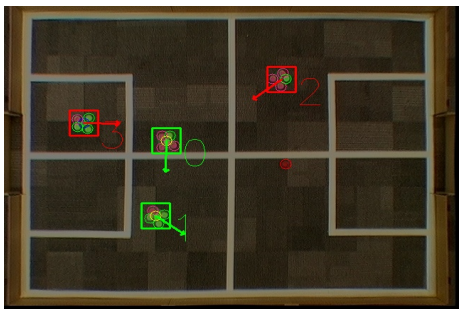
1. The dictionary of the camera capture settings (brightness, contrast, hue and saturation) are read from `room0/1.txt`, pitch dimensions from `pitch0/1.txt`, and color thresholds from `color0/1.txt`.
2. The aforementioned settings are used, a frame is read, and the Gaussian blur is applied to create more solid features.
3. A unique application to speed up the feed is the variable `world.undistort` which lets the strategy to conditionally remove the barrel distortion when it is unnecessary.
4. All color thresholds are added to the same mask and K-means is used to group them together to form various spots in the image.
5. Then the color is found from the center pixel of the cluster. The spot is either kept or removed depending on the minimum area for that color which varies as some colors are more difficult to see.
6. The individual methods required for finding the robots and ball are then implemented as outlined below.
7. When the vision system is closed using the escape key, the most recent calibration values and the current camera settings defined by the slider bars are saved and can be used on the next execution.

4.1.1 Finding the ball

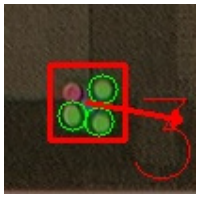
The algorithm looks for 10 red spots and checks through them in the order of descending area. To prevent a pink being misclassified as the ball, each red spot is checked whether it exists close to the centres of the robots. As the robots can shield the ball from view, a method is used which determines whether a specific robot is in range of the ball. If so, when the ball is shielded, an imaginary ball is placed along the orientation vector of that robot until the ball is found. This method is in place for all robots except for Venus because the sensor is being used instead to determine whether Venus has the ball.

4.1.2 Finding the robots

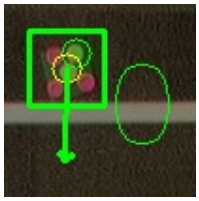
Due to the varying light intensities over the pitch a highly tolerant method of identifying robots is used. The robot identities are pre-defined and dependent on the choice of the center and corner spot as seen on the right. Numbers are assigned sequentially to our robot, teammate, first enemy, and second enemy.



There are two independent ways the robot can be identified:

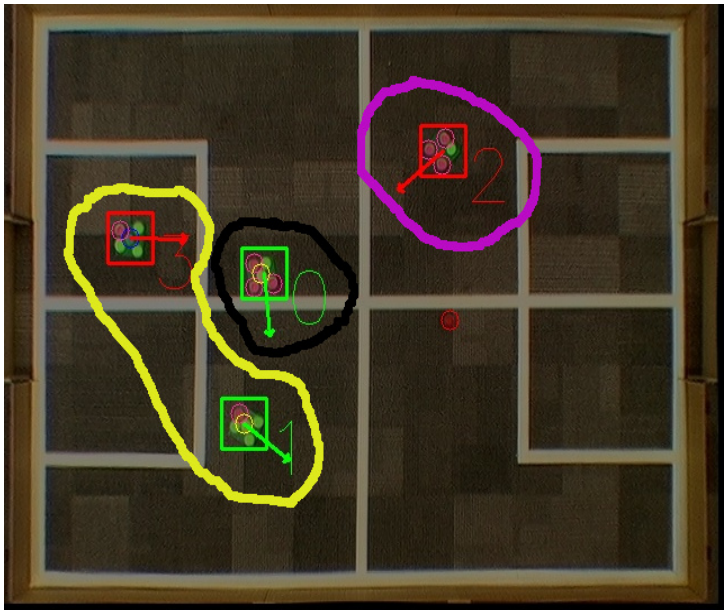


The three spot method: Finds the largest of the three distances between spots, then draws a vector from the midpoint of this edge to the spot not included in the edge. The orientation is then computable by rotating this vector by a fixed amount. Then, the robot center is calculated using the average of the spot centres.



The two spot method: As each spot is distinguishable, a vector can be constructed between the center spot and the corner spot and rotated a fixed amount to find the orientation. Then, the robot center is calculated using the center spot.

As there will always be two robots with the same plate configuration required for the methods above, the algorithm needs some of the robots to be identified using more information. As seen above, the robots from the same teams will have the same two spot plate configuration. Also, for the three spot method the robots 0, 2 and 1, 3 will have the same plate configurations. To solve this, the spots are initially grouped together into potential robots in the order of descending areas. The groups are run through several filters for each type of robot accepting the groups if there exists a specific numbers of coloured spots. Each spot that is found is circled with its respective color on the vision feed. The sets of spots on the filers bellow correspond to finding the robot zero.



FILTER 1 { ● ● ● ● }
To pass into here it must have a correct team spot and no other visible team color. It must also have three of its three spot color.

FILTER 2 { ● ● ● ● , ● ● }
To pass into here it must have a correct team spot. It also must have more than one of its three spot color or less than two of its corner spot color.

FILTER 3 { ● ● ● ● , ● ● , ● ● ● }
To pass into here no team spot is required, it must only have more than one of its three spot color or less than two of its corner spot color.

As each identity is found, its corresponding filters are blocked and its position is noted so that a robot does not get detected in the same place as the one that is already detected. Once any group of spots gets through a filter of a given identity, the identity of that robot is then updated using either the three spot or two spot method depending on what information is available. If a robot is not found, it keeps its original position. To handle cases where robots are lifted off the pitch, the system creates a ghost robot marked in blue on the vision feed. This tells the strategy to ignore the contribution to the game of that robot but the robot continues existing on the pitch in the vision thread.

4.2 Strategy

4.2.1 Higher Strategy

At a higher level our strategy system consists of a list of states, triggered in a specific order of priority. The states and their triggers can be seen in Table 2.To have a better understanding of the world we use the following tools in the to trigger the states:

isSafeKick: First the intended ball trajectory vector is calculated. Second two more vectors are calculated between the source of the kick and each individual defending robot. Using a dot product the angle between these two vectors and the trajectory is calculated. The method returns True if this angle is less than 30 degrees.

isCloserToGoal: This Method returns True if venus is in the best position to defend the goal and false if the friend is. We find the equation of the line to the center of the defending goal to the position of the enemy robot in possession of the ball. Then we find the perpendicular distance from both venus and our team mate to that line. If the robots do not lye perpendicular we use the distance to the attacking enemy instead. The method returns the best positioned robot.

hasBallInRange: This Method is used to check if a certain robot has the ball close to it and thus deduce that robot would be in possession of it. The method returns true if the position of the ball is within 15cm of the robot. Note here, for Venus this method is overridden by the check from the IR sensor as it is a more reliable.

goalsideRobots: When trying to find the best position to move to receive a pass it was necessary to know about the enemy robot positions. To deduce whether they were not going to influence the pass a vector is constructed between both our team mate and venus. Two vectors perpendicular to this line are then constructed that pass through venus and our team mate respectively. These two vectors construct a channel and if an enemy robot lies within this channel it is not 'goalside'.

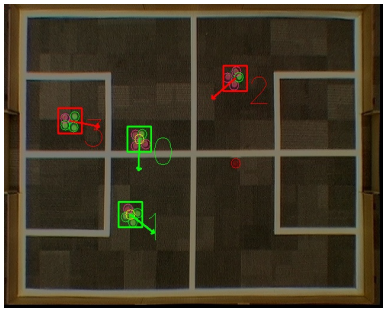
Priority	**State**	**Trigger**
1	ATTACK_GOAL	Venus has ball and goal **isSafeKick** is True for venus
2	ATTACK_PASS	Venus has ball and goal **isSafeKick** is False and **isSafeKick** is True for passing to friend
3	ENEMY1_BALL_TAKE_GOAL	Enemy 1 has ball and venus **isCloserToGoal**
4	ENEMY2_BALL_TAKE_GOAL	Enemy has ball and venus **isCloserToGoal**
5	ENEMY_BALL_TAKE_PASS	Enemy has ball and friend **isCloserToGoal**
6	FREE_BALL_YOURS	**hasBallInRange** False for every robot
7	RECEIVE_PASS	Friend **hasBallInRange** and pass **isSafeKick** for friend
8	FREE_BALL_NONE_GOALSIDE	No Enemy is in **goalsideRobots**
8	FREE_BALL_1_GOALSIDE	Enemy 1 is in **goalsideRobots**
8	FREE_BALL_2_GOALSIDE	Enemy 2 is in **goalsideRobots**
8	FREE_BALL_BOTH_GOALSIDE	Both Enemy are in **goalsideRobots**

Table 2: States available in the strategy system

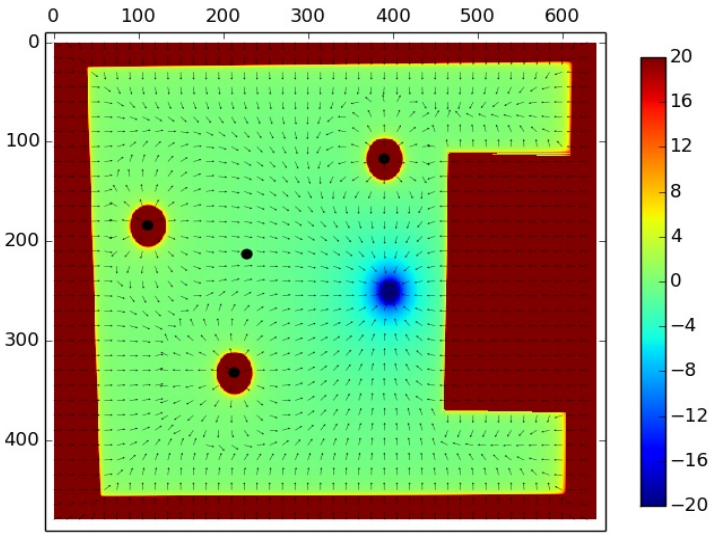
4.2.2 Potential fields

The following graphs were plotted using the command `map STATE_NAME` which is ideal for visualisation and quick testing of newly defined fields. The graphs below contain quiver plots of the force acting on Venus at a given point in space. This is drawn on top of a heat map of the value of the potential field at a given point.

`FREE_BALL_YOURS`

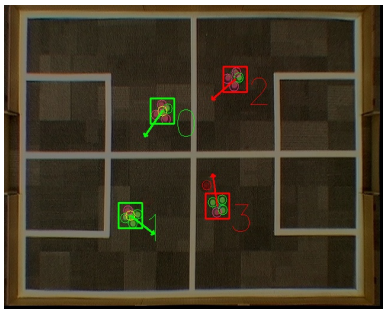


Forces due to obstacles: The walls exert a force governed by a $1/r^3$ law on the pitch side of the wall where r is the perpendicular distance to the wall. On the opposite side of the wall an attractive potential $-1/r^3$ is used instead to pull any robots into the pitch. An identical field is used in the penalty box, however, to avoid getting stuck in a local minima at the sides, the field inside the box pushes the robot to the front only and does not attract it back over the side it came from. As the box is finite, any position that is not perpendicular will exhibit a similar force, only r will be the distance to the closest corner. The robots use a $1/r^2$ law where r is the radial distance from the edge of the robot represented by the solid circle in red.



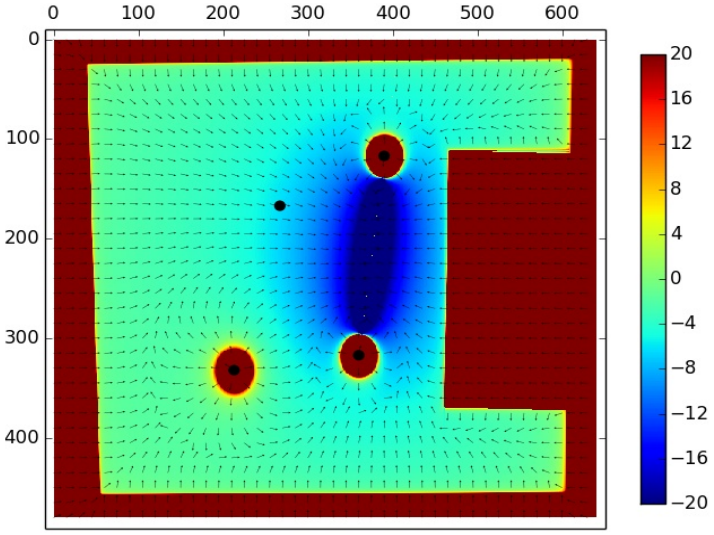
Grabbing: The ball uses an attractive radial field of $-1/r^2$. The amplitude of the field is larger than that of the robot to enable fast navigation. Once a potential of -4 is reached, the grab is initiated using quantised distance and angle motions enabled by the motor encoders. The -4 value has been chosen as it implies the ball is clear of any obstacles as otherwise the potential value would be higher.

ENEMY_BALL_TAKE_PASS



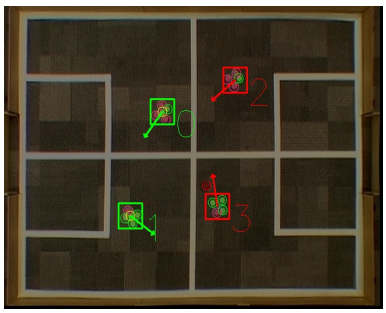
Blocking pass: A finite axial field is used to enable smooth motion during the block of a pass from any point in the pitch. The points in question are first rotated so that the field is flush with the x-axis and the force is calculated using the following equation and rotated back. d is the perpendicular distance, a is the parallel distance to the end with the smaller x value and b is similar dimension in the exact opposite direction.

$$\left(\frac{1}{\sqrt{b^2+d^2}} - \frac{1}{\sqrt{a^2+d^2}}, \frac{b}{d\sqrt{b^2+d^2}} + \frac{a}{d\sqrt{a^2+d^2}}\right)$$

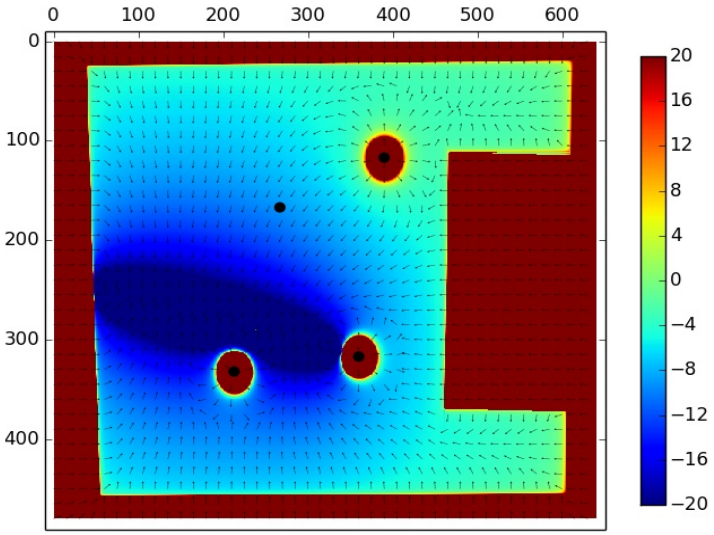


Interceptions: When the current potential of Venus reaches -12, the block is satisfactory and the robot faces the ball with its grabber open. When the ball is shot as it is moving, the FREE_BALL_YOURS state is activated causing an attraction to the moving ball.

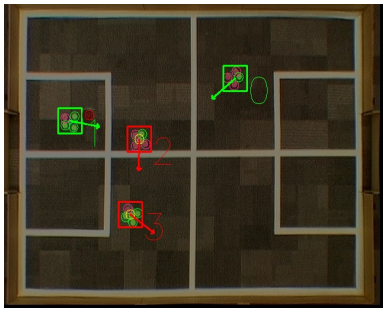
ENEMY2_BALL_TAKE_GOAL (ENEMY1_BALL_TAKE_GOAL)

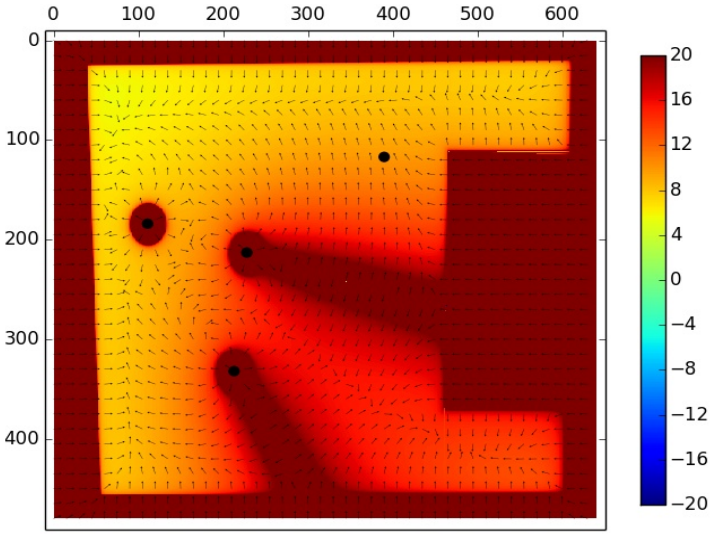


Blocking goal: The same field is used from the state above but for a block between the goal and an enemy robot. The current satisfactory potential for this block is -14 in order to be sure to block the whole goal.



FREE_BALL_NONE_GOALSIDE (FREE_BALL_1_GOALSIDE, FREE_BALL_2_GOALSIDE)





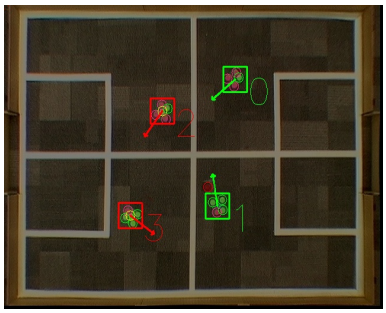
Optimising position: Given your team mate is either fetching or has the ball you want to find the best position to receive a pass. Two fields are added in order to implement this:

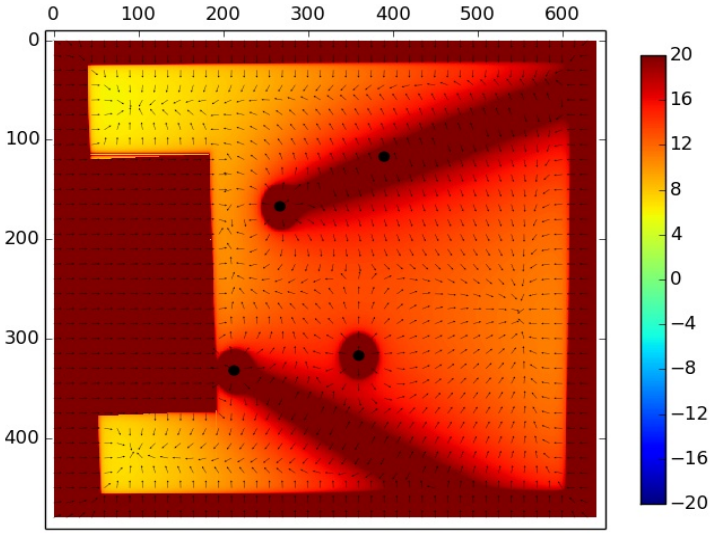
1. The shadowed array blocking the pass.
2. The shadowed array blocking the goal.

This state represents a double blocked pass. An identical type of field is used in the defence states, however, one end is placed at the start of the shadow and the other three pitch lengths away. This is so that Venus is repelled perpendicular to the shadow and also parallel around the enemy robots if needs be.

Once a satisfactory potential of 6 is reached, Venus will turn and wait to except the pass. As the other robots move, Venus will keep trying to minimise his potential until a value of 6 is obtained.

FREE_BALL_BOTH_GOALSIDE (FREE_BALL_1_GOALSIDE, FREE_BALL_2_GOALSIDE)





Local minima: Whilst optimising position Venus can get stuck as enemy players close up to defend the same shot. To deal with this, a timer is used so that if Venus has been sitting in a unsatisfactory potential for too long, we remove the least import field. In this case, the furthest player blocking the goal.

Handling opponents that divide up defensive positions: As outlined in the state above, this graph represents a double blocked goal and the final two states that are not shown are a mixture of this state and the state above.