Imperial College London

MEng Final Year Project Report

Imperial College London

Department of Electrical and Electronic Engineering

An Intelligent Scrabble Board for Alchemist 2024

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Chapter 1

Introduction

Scrabble®is a popular board game in which 2-4 players compete by forming words with lettered tiles on a 15 by 15 grid, interlocking like words in a crossword puzzle. The English version of the game is played with 100 tiles, including all 26 letters of the alphabet as well as 2 blank tiles which can represent any letter. Despite being created close to 80 years ago [1], the game remains popular today, topping the UK sales charts in 2008 [2], and can be found in over 50% of UK homes [3]. Scrabble also has a thriving competitive scene, with tournaments across the world held each week [4]. The World English Language Scrabble®Players Association (WESPA) is the overarching global body for English-language national Scrabble associations, and provides an official structure for the international Scrabble community [5]. Alchemist Cup 2024 is an international competition in affiliation with WESPA, with 10 different countries competing over 45 matches [6].

The organiser for Alchemist Cup 2024 is sponsoring this project to modernise the way competitive Scrabble is broadcast. Currently, games are live-streamed using several cameras to capture the board, player racks and players themselves, and the state of the game is manually transcribed into presentation software by the broadcasting team. An example of this setup is shown in figure 1.1.

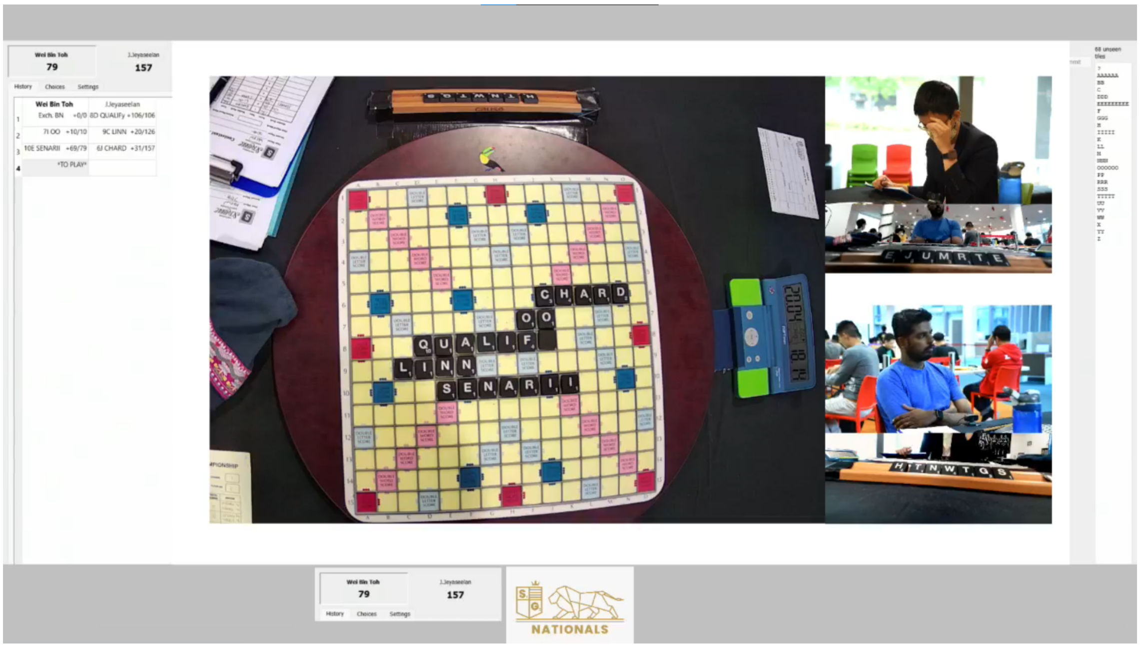

Figure 1.1: Match from the 2022 Singapore National Scrabble Championship

This poses several limitations when compared to tournaments in other games, such as chess, which detract from the viewer experience. Casters are unable to quickly switch between concurrent matches as only a single game is tracked and visual annotation of future moves is difficult. The goal of this project is to design a solution allowing for the automated digitization of competitive Scrabble, which is implementable for Alchemist Cup 2024.

Recently, several WESPA tournaments have been played on an online Scrabble platform Woogles, including the 2022 Youth Cup [7]. Woogles is developing an API to allow Scrabble moves to be uploaded to the site in real-time, allowing for casters to annotate potential moves, and displaying possible plays using the Macondo crossword AI [8]. The project's sponsor would like the solution developed in this project to interface with the Woogles API so that it can be integrated in the event's broadcast.

1.1 Requirement Capture

Due to the open-ended nature of the project, there are several possible solutions to capture the game state, which are discussed in chapter 3. In order to distinguish between them to find the most suitable one, it was important to obtain a well-defined set of requirements from the sponsor, which was accomplished over repeated meetings. Due to its intended use in tournament play, it is critical that the solution correctly encodes and conforms to WESPA's tournament rules, which are included in Appendix A.

The full set of project requirements were broken down as follows in order of importance:

Game State All relevant information regarding the state of the game must be captured with a high degree of accuracy (99.9%), with appropriate processes to verify this performance prior to the start of a match. There should be no more than a 1 second delay between the game state captured and the true state of play, and this information must be represented visually such that it can be included in the tournament live-stream, ideally through the Woogles API. Necessary information includes:

- The tiles played on the board
- The tiles in the players' racks'
- The values of any blank tiles played on the board

Top Scrabble players score $\sim$ 35 points per turn (excluding tile exchanges), and between 330-450 points per game [9], meaning the typical game should take under 26 turns to complete. Given that exchanges are rare [10], it is safe to assume that matches finish within 28 turns. Therefore, a solution capable of detecting the game state correctly with a probability of 99.9% would have 97% likelihood of recording a game without errors. Whilst this means that over the course of the tournament, there is a 75% likelihood that at least one game has an error, they should be rare enough that they could be easily solved through manual intervention, or preferably repeated measurements from the board.

Player Experience The solution must have a minimal impact on the players, ideally conforming to WESPA's equipment preferences:

- Tiles achieve both tactile and visual indistinguishability.
- The board can revolve with minimal disturbance to items on the playing table.
- The board material is non-reflective.
- The number of tiles on a player's rack must be clearly visible to the opponent.

Cost and Production The cost of the solution should not exceed £500 per board, must be manufacturable in a batch of 25 by December 2024.

Word Challenges Competitors may challenge the validity of the words played by their opponent in the previous turn. The solution must therefore ensure that:

- Valid and invalid words are distinguishable from one another.
- A list of currently challengable words must be maintained and made available to competitors when requested.

Chapter 2

Background

As mentioned previously, there are multiple solutions to tackling this problem, and several different approaches were considered. As such, the background in this section is quite broad to provide the required context to understand the decisions made in chapter 3.

2.1 Existing Hardware Solutions

2.1.1 DGT Chessboards

Digitizing popular board games for competitive play has been done before, most notably in the case of chess, with the International Chess Federation (FIDE) using electronic boards since 1998 to allow chess games to be followed in real time via the internet [11]. These boards, developed by DGT [12], are able to identify the different chess pieces and their positions on the board using their patent-registered sensor technology [13], solving a very similar problem to identifying the type and position of tiles on a Scrabble board. Chess pieces contain a passive LC circuit with a specific resonance frequency in the 90Hz-350kHz range depending on its type. The file and rank of a square are selected by analogue switch multiplexers, allowing a particular square to be isolated, and corresponding transmission and reception coils interact with the LC circuit in the piece on the square. The resulting resonance signal obtained on the receiving coil is then converted by the controller firmware into the corresponding chess piece in around 3ms [13]. An example of this operation can be seen in Figure 2.1, where the control device (11) selects a particular transmission coil (18) and reception coil (19) via the multiplexers (10) to measure the resonance signal of the coil in the chess piece (16). Each reception coil comprises of several windings (17) to increase its sensitivity.

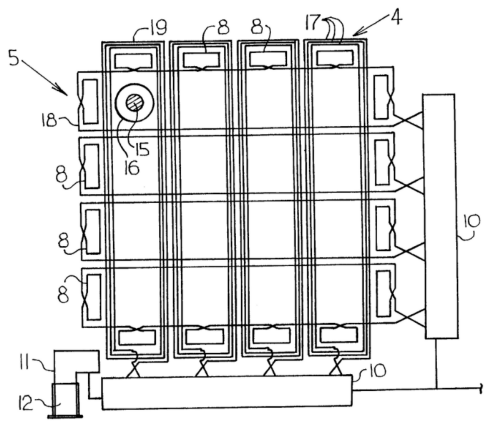

Figure 2.1: Digitised chessboard layout [14]

One issue with this solution is that the transmission and reception coils also generate a resonance frequency, which interferes with the resonance frequency of the resonance coil in a playing piece. The effect of this interference increases as the topography of the coils around the selected playing square becomes less symmetrical, meaning that the further from the center a piece is, the greater the inaccuracy. This asymmetry is compensated for by the windings (8) in the transmission coil, which generate an additional magnetic field that supplements field produced by the transmission coil to render it practically symmetrical. This interference problem would be exacerbated in the case of Scrabble, as not only are the squares roughly a quarter of the size of those in chess, requiring a denser layout of coils, but the play area is a 15 by 15 grid, rather than an 8 by 8 one, leading to greater asymmetry when measuring tiles on the edges of the board. Furthermore, these boards cost over £600 [15], which already exceeds the budget set by the sponsor.

2.1.2 MSI Smart Scrabbleboard

There also exists a smart scrabble board, which was used in the 2012 MSI Prague tournament [16], based on Radio-Frequency Identification (RFID) technology. The tiles are embedded with RFID tags encoding which letter it is, and each square on the board is equipped with an RFID antenna which can detect the tile placed on it. The operation of such an active reader passive tag (ARPT) system is shown in Figure 2.2, where a passive tag consisting of an antenna and application specific integrated circuit (ASIC) chip obtains power from the signal transmitted by the RFID reader. The tag then sends data back by switching its input impedance between a high and low state to modulate the backscattered signal.

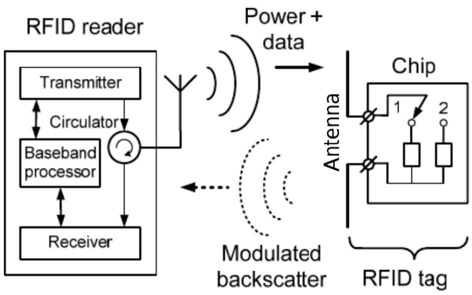

Figure 2.2: ARPT RFID system overview [17]

The MSI board contains nine embedded circuits which cycle through the different antennas to check if a tile is placed on it, and allows a full picture of the board to be constructed in 974ms [18]. The player's racks also included an RFID circuit board, capturing which tiles the players drew. Unfortunately, the combined 100 tags for each tile and 255 antennas for per square on the board make this solution prohibitively expensive, and cost over £20,000 to produce [18].

2.2 Digital Image Processing

With the emergence of low-cost processors and camera peripherals, as well as modern advances in image processing algorithms and computer vision, real-time digital image processing has become more accessible than ever before [19], and offers an alternative approach to tackling the issue of game state capture. The application of digital image processing techniques in scoring scrabble games has already been explored several times [20] [21] [22] [23]. Commercial solutions also exist, such as Scorable [24], a mobile application to automate game scoring. After applying various pre-processing algorithms to isolate the squares on the game board, these solutions use Optical Character Recognition (OCR) to identify the tiles, to varying degrees of success. The use of a k-nearest neighbours algorithm by David Hirschberg from the University of California, based on an earlier work from the University of Sheffield [22] only achieves an classification rate accuracy of 67% [23], and is too unreliable to be considered for this particular application. However, the pre-processing techniques used in capturing the board remain relevant, and are covered in greater depth below. The use of convolutional neural networks (CNN) have a much greater potential, with one solution obtaining over 99.9% accuracy [25]. Although closed-source, the original developer of Scorable, Viliam Vavro, has confirmed via email exchange that their recognition model can perform at practically 100% accuracy in an environment with even lighting and English tiles. As such, an imaging-based solution appears to be promising, and systems using an embedded Raspberry Pi and camera, as well as the existing camera setup are considered in chapter 3.

2.2.1 Optics

Optics form a key component of machine vision, are and necessary to ensure that the appropriate illumination, lenses and sensors are selected to capture all the information relevant to a task [26]. The following parameters are of particular importance in ensuring the game state can be captured:

- **Field of View (FOV)** refers to the viewable area of the object under inspection, and is commonly reduced to the horizontal or vertical dimension for ease of calculation. If both values are cited, the horizontal value is given first by convention. For this particular application, the FOV is 322mm by 322mm for the board and 265mm by 20mm for the player racks.

- **Working Distance (WD)** refers to the distance from the front of the surface of the lens to the object under inspection. For optics within the board or racks, the WD is limited to 10cm to avoid becoming too cumbersome for the players. For optics outside the board, the current setup uses a WD of $\sim$ 10cm for the racks and $\sim$ 100cm for the board.

- **Resolution** is an imaging system's ability to reproduce object detail, with a need to capture smaller details requiring a higher resolution. This value can be estimated by dividing the number of horizontal or vertical pixels on a sensor into the size of the object one wishes to observe. The minimum resolution required will depend on the type of image processing performed. Lighting plays an important role in the resolution of an optical system, and is inversely proportional with the wavelength of light; best results are typically achieved using blue (470nm) light [27].

- **Depth of Field (DOF)** refers to the maximum object depth that can be maintained in acceptable focus, as shown in Figure 2.3. When trying to capture the state of a game of scrabble, DOF can be kept quite low as the tiles on the racks and board essentially occupy a plane. This means that DOF can be traded off against more important parameters such as resolution, which is inversley proportional to DOF [27].

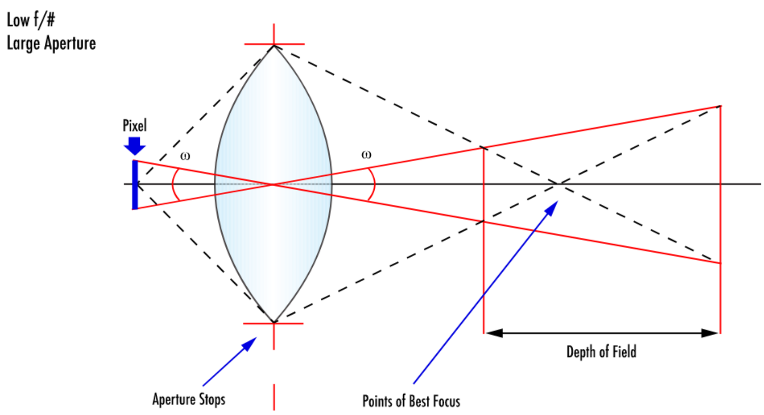

Figure 2.3: Depth of field [28]

To ensure that an optical system is able to perform on a particular FOV with a target WD, an appropriate combination of sensor and lens must be selected. From a physics point of view, the focal length f of a lens is defined as the distance from the back surface of the lens to the plane of the image formed of an object placed infinitely far in front of the lens, meaning that given the length of a sensor l in a given dimension, the angular field of view (AFOV) can be derived as:

$$\text{AFOV} = 2 \times \tan^{-1}\left(\frac{l}{2f}\right) \tag{2.1}$$

Furthermore, as can be seen from Figure 2.4, the AFOV required for a particular FOV and

WD can be found as:

$$\text{AFOV} = 2 \times \tan^{-1}\left(\frac{\text{FOV}}{2 \times \text{WD}}\right) \tag{2.2}$$

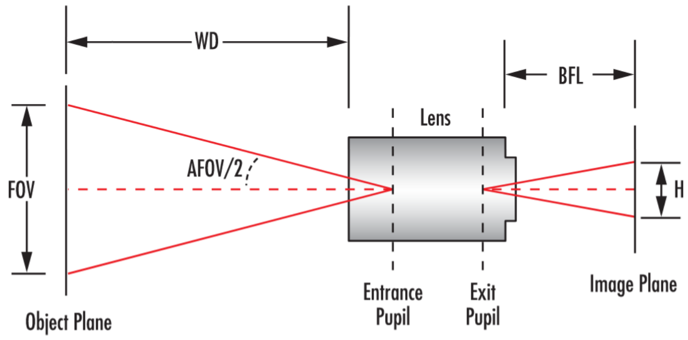

Figure 2.4: Relationship between FOV, WD and focal length for a given sensor [29]

Combining Equation 2.1 and Equation 2.2, one can obtain the focal length required to achieve a target WD and FOV:

$$f = \frac{(l \times \text{WD})}{\text{FOV}} \tag{2.3}$$

In practice, focal length is measured as the distance between the optical centre of a lens and the image sensor, meaning that Equation 2.3 can only serve as an approximation for the appropriate focal length. Furthermore, using an imaging system within the Scrabble board places extreme conditions on the FOV to WD ratio, as ideally the thickness of the board needs to be minimised whilst keeping the area constant, meaning a short focal length is required. Short focal length lenses typically have greater distortion, which can further influence the real AFOV, and have difficulties covering medium to large sensor sizes, restricting the choice smaller sensors reducing resolution [29]. Additionally, for optimal performance, WD should be 2 to 4 times the FOV [30], leading to further degradation in resolution.

It is important to note that distortion does not reduce the information on an image, but misplaces it geometrically. Rectifying distortions stemming from the use of wide-angle or fisheye lenses has been extensively studied in literature, and there exist algorithms to correct such distortions efficiently [31]. Lighting can also influence distortion, with shorter wavelengths leading to reduced distortion [32]. Given the importance of lighting, controlling the environment of an imaging system significantly improves its reliability and performance [30].

2.2.2 Pre-processing Algorithms

Once a clear image is obtained, there are a range of relevant image processing algorithms that are useful in capturing the game board and tiles. For 2 dimensional images, most algorithms are defined by the 2D convolution of the image itself with a small matrix, often referred to as the kernel. In essence, the kernel defines the function between a pixel in the output image and its neighbourhood of pixels in the input image. Odd-sized kernels are generally used so that the origin of the kernel can be defined as its center. For some $2b+1$ by $2a+1$ kernel ω, a pixel in the resulting image g from the application of the kernel on input image f is defined as follows:

$$g(x, y) = \sum_{dx=-a}^{a} \sum_{dy=-b}^{b} \omega(dx, dy) \cdot f(x - dx, y - dy) \tag{2.4}$$

Coloured images are made up of multiple channels of pixels, adding a third dimension to the image. These are processed with concatenations of kernels, called filters, with each kernel assigned to a particular channel. Whilst the additional information that coloured images provide can be useful, and may be required to distinguish between an empty square and a blank tile, they are nosier and significantly increase the computational complexity of operations [33]. As such, it is often suitable to convert images to grayscale before applying the algorithms below, particularly if an embedded solution with limited computational resources is chosen. This is typically done using the luminosity method, which returns an average of the RGB pixel values weighed by the significance of each colour on human perception [34].

Noise Reduction

Noise in digital image processing refers to unwanted variations in the pixel values caused by factors such as sensor noise, compression artifacts or transmission errors, which degrades the quality of an image and making it more difficult to extract useful information. Given that reliable performance is a critical requirement in this project, reducing noise is key in ensuring that the system is robust, and is often the first step of any image processing algorithm [35]. The most common way to reduce noise is to perform spatial filtering using a Gaussian filter to average pixel values in a local neighbourhood, as it preserves image details more effectively than box filters whilst retaining high computational efficiency. The kernel for this operation is generated by a 2D Normal distribution (as shown in Equation 2.5) around its center, and is parameterised by its standard deviation σ, which can be increased for a stronger reduction of noise, at the cost of greater smoothing leading to a loss in detail. An example of the Gaussian filter in action is shown in Figure 2.5.

$$G(x,y) = \frac{1}{2\pi\sigma^2} e^{\frac{-(x^2+y^2)}{2\sigma^2}} \tag{2.5}$$

Given that the optical system in this project will be dealing with a fixed FOV over a period of time, more complex, non-linear filters incorporating temporal as well as spatial denoising could be relevant if additional noise reduction is necessary [36], although their computational complexity may make them infeasible for an embedded approach.

Figure 2.5: Application of Gaussian filter ($\sigma = 2$) on cameraman standard image

Edge Detection

Edge detection is a technique to determine the boundaries of objects within an image by detecting discontinuities in brightness [37]. This allows physical phenomena to be localised, which is essential for capturing the state of the game board and racks. There have been numerous algorithms that have been developed for this purpose, and it is important to develop a working knowledge of their operation to understand how to maximise their performance. Most edge detection methods rely on finding local maxima of the image gradient, which can be approximated by applying first-order derivative kernels [38]. Such operators include Robert's cross operator, the Prewitt operator and the Sobel operator, although the Sobel operator is the more commonly used to its superior noise-suppression characteristics [39]. To compute the gradient magnitude and direction, the Sobel operator defines a pair of kernels which are applied to the image to obtain the first derivative in the horizontal (G_x) and vertical directions (G_y), which are shown in Equation 2.6.

$$G_x = \begin{bmatrix} -1 & 0 & +1 \\ -2 & 0 & +2 \\ -1 & 0 & +1 \end{bmatrix} \qquad G_y = \begin{bmatrix} +1 & +2 & +1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix} \tag{2.6}$$

From these resulting images, the edge gradient G and angle θ can be computed as $G = \sqrt{G_x^2 + G_y^2}$, $\theta = \arctan \frac{G_y}{G_x}$. Despite outperforming other operators, this process is still sensitive to noise, producing both false positives and negatives.

The Canny edge detection is a multi-stage algorithm used extensively in engineering applications, relying on the Sobel operator and leveraging several techniques to reduce the impact of noise [40]. The algorithm can be broken down as follows:

1. *Noise reduction:* A Gaussian filter with suitable parameters is applied to the image.

2. *Intensity gradient:* The Sobel operator is applied to determine the magnitude and direction of edge gradients.

3. *Non-maximum suppression:* Candidate edge points are verified to be local maxima in the gradient direction, which is orthogonal to the edge. Non-local maxima are discarded, resulting in a binary image with thin edges.

4. *Hysteresis thresholding:* Two thresholding parameters, $minVal$ and $maxVal$ are used to decide which edges will be kept. Any edges with an intensity gradient $g > maxVal$ are categorized as definite edges, and any edges with $g < minVal$ are definite non-edges. Any pixels in between the two thresholds are only considered edges if they are connected to a definite edge, else they are also ignored.

This algorithm has many tunable parameters affecting the various stages, which are application specific and need to be set correctly in order to ensure reliable performance. However, once these are set correctly, the Canny algorithm provides a computationally efficient, robust method in detecting edges with a high degree of accuracy [40]. OpenCV, a popular python based computer vision library, provides an implementation of Canny edge detection [41] which was used with default parameters to obtain Figure 2.6.

Figure 2.6: Application of Canny edge detection on cameraman standard image

Structured edge detection is a more novel edge detection algorithm which applies random decision forests to predict local edge masks, and once trained was able to achieve superior real-time performance to the Canny algorithm [42]. Although training a model for edge detection in this specific application is outside the scope of this project, should the Canny algorithm prove to be a performance bottleneck in the final system a using structured edge detection with a pre-trained model provides an alternative computationally inexpensive solution.

Contour Detection

Contours are curves joining all continuous points along a boundary, having same color or intensity, and are particularly useful for shape analysis and object detection and recognition [43]. Contour detection aims to detect these curves in an image, providing a compact description of its shape including information such as its centroid and bounding rectangle, which in this application is particularly useful for isolating the letters on tiles for categorization. Although several approaches exist, Satoshi Suzuki's border following algorithm is a popular, robust and efficient algorithm building on edge detection [44] which is implemented in numerous image processing libraries such as OpenCV [45]. In order to obtain high accuracy when applying this algorithm, it is important to use a binary image, such as one produced by the Canny edge detection algorithm [46]. As this algorithm does not depend on tunable parameters and is primarily a function of the binary image provided as input, a deep understanding of its operation is not particularly relevant. If its performance is not reliable enough, and cannot be improved through adjustments in upstream processing, alternative contour detection algorithms may be considered.

Feature Detection and Matching

Although no exact, universal definition exists, features typically refer to "interesting" points on an image, which are ideally invariant under changes in illumination, translation, scale and in-plane rotation. Once identified, key elements of this feature are encoded in a feature description, which can then be used to identify the same features in other images, essentially providing a mapping from one image to the other, in this case providing an effective and robust method of isolating the Scrabble board. These feature descriptions are the core part of matching techniques, as perhaps obviously the performance of the matching algorithm is a function of the description quality. The choice of feature detector, which generate these descriptions is therefore a key parameter in the performance of the overall system. A wide range of feature detection algorithms exist, and developing a working understanding of their properties is essential in ensuring appropriate detectors are used.

Corners are regions in an image with a large variation in intensity in all directions, making them strong features [47] as they are essentially unique points. Harris corner detection is an early feature detection algorithm focused on identifying these corners, relying in part on the Sobel operator mentioned in previous sections to obtain the image derivatives [48]. Improvements to this algorithm were later made by Shi and Thomasi which uses a different selection criterion which is more computationally efficient and ensures better features are chosen [49]. Although they are rotationally-invariant, as corners are unaffected by a change in orientation, changes in scale can affect the properties of a corner, leading to a rapid deterioration in performance as the scale of features is adjusted [50]. This may be an issue for this application, as there may be variance in the distance between the camera and the board which although minimal could degrade the reliability of the system. Strict constraints on the positioning of the camera could be imposed to mitigate this issue, although the system would remain less robust to mistakes in setup, and hence alternative methods would be preferable.

Scale-Invariant Feature Transform (SIFT) is able to achieve scale-invariance through the use of scale-space filtering [51], in which Gaussian filters smooth the image to different levels of details representing different scales allowing features stable in scale-space to be identified. This filtering is approximated using a difference of Gaussian, which although more efficient than Laplacian of Gaussian (LoG) that would be ideally required [51] remains quite costly, making the algorithm computationally slow compared to those discussed previously and potentially infeasible for the real-time system this project is designing. However, the descriptors returned are highly robust and perform incredibly well compared to other techniques [52]. Speeded-Up Robust Features (SURF), as the name suggests, is a more efficient version of SIFT, approximating the LoG more aggressively with a box linear filter, as well as other optimisations to obtain a 3 times speed improvement, whilst retaining comparable performance to SIFT [53]. The matching time of these algorithms can be further improved through the transformation and condensing the feature space, allowing a single computation of the Hamming distance and reducing the memory footprint through the application of Binary Robust Independent Elementary Features (BRIEF) in conjunction with these matching algorithms, which lead to a 4- to 13-fold speed-up over SURF depending on the level of compression [54]. However, this technique is not-designed to be rotation invariant, and although capable of handling small perturbations in angle [54] would lead to significant deterioration in performance, and as such was deemed unsuitable for this application.

If the performance of SIFT and SURF prove inadequate, alternative machine learning-based techniques such as Features from Accelerated Segment Test (FAST), which achieve more rapid classification whilst retaining the rotation- and scale-invariant properties [55]. This algorithm uses a decision tree classifier to speed up the detection of corners, with higher accuracies obtained when trained on target application domain, although pre-trained general classifiers can also be used, as well as relying on a tunable threshold value for the intensity of corners and suffering a higher sensitivity to noise [55], making it less robust than SIFT or SURF. Binary Robust Invariant Scalable Keypoints (BRISK) builds on FAST, as well as incorporating a BRIEF-like feature descriptor for a matching rate an order of magnitude faster than SURF and almost equivalent reliability, only performing slightly worse for large transformations [56]. As well as inheriting the threshold parameter from FAST, classification speed vs robustness to scale-invariance can be traded off with another parameter which essentially defines the number of scales the image is sampled at to obtain reliable features [56]. It is not possible to determine which of the previously discussed detectors is the most appropriate for this project solely based on theoretical considerations. Rather, the trade offs between the different algorithms present a systematic method in which they can be tested experimentally to determine the most robust algorithm that meets the performance requirements of the system.

Once a feature description algorithm is selected, matches are typically found by determining the "closest neighbour" to the target feature space, in which the distance metric selected depends on the feature description. For SIFT and SURF, the L2-norm typically provides the best results, whilst binary string descriptors like BRIEF and BRISK can use Hamming norm instead [57]. OpenCV also offers a Fast Library for Approximate Nearest Neighboors (FLANN) based matcher which is optimized for large datasets with high-dimensional features [57], although this would likely be unnecessary for the purposes of detecting the game board. Given enough matches between the two target objects, a homography, which is a 3 by 3 matrix defining the transformation between two points, can be computed to best fit all the matches, allowing the inverse transformation to be applied to matched object such that it matches the target object. This transformation on the board can introduce a parallax error to game pieces on it, as can be seen in Figure 2.7, although this is unlikely to pose an issue in this application as the camera line of sight will be vertical.

Figure 2.7: Homography applied to obtain bird's eye view of chessboard [58]

2.2.3 Convolutional Neural Networks

Convolutional Neural Networks (CNNs) are a type of deep learning neural network architecture that is specifically designed for image recognition or other tasks that involve pixel data, inspired by the human visual cortex [59]. The application of CNNs to optical character recognition has been studied extensively [60], and the use of either pre-trained or custom-fit CNNs to the problem of categorizing scrabble tiles is essential in attaining the tight accuracy and reliability requirements of this project.

CNNs are comprised of three primary building blocks, convolutional layers, pooling layers and fully-connected layers. Convolutional layers employ the familiar convolution operation, but now the elements of the kernel are parameters which are optimised during training, allowing local patterns in small 2D-windows of the input image to be learned [61]. The results of the convolution are then passed through an activation function, which allow non-linear behaviour to be captured. In deep learning applications, the `relu` function, which simply restricts values to be non-negative, is the most popular [61], and as such would most likely be selected . These operations are performed independently over each channel of the image, although in this application only 2D gray-scale images will be used, as colour will be removed in the input pre-processing.

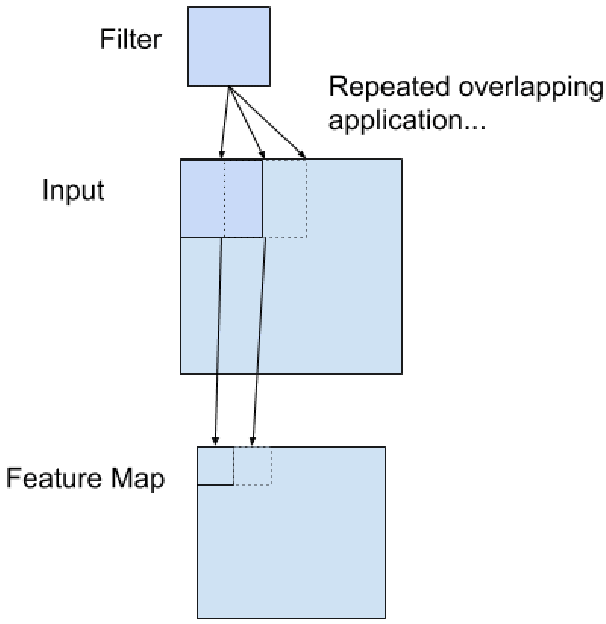

Figure 2.8: An example of a 2D convolution operation [62]

The resulting feature map is then down-sampled using pooling layers which reduce the spatial resolution to increase the invariance of the features to small translations in the image. The down-sampling also allows spatial-filter hierarchies to be built, where successive convolution layers inspect increasingly larger windows, with the final layer accessing information from the totality of the input. Although this down-sampling can be achieved using strides in the convolution layers, in which the kernel operation "jumps" over elements in the grid, or average pooling which takes the average value of each channel over a given patch, max pooling where the maximum value in each patch is selected tends to perform best [61].

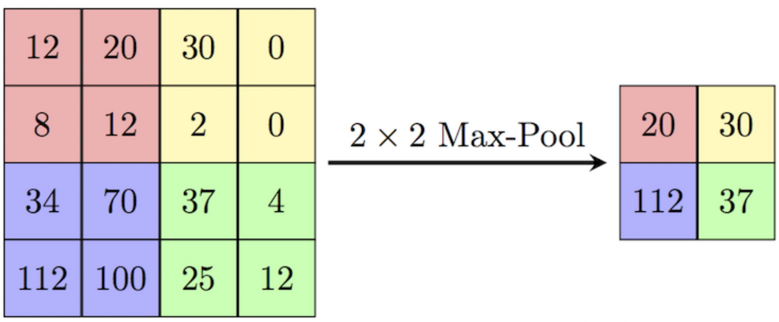

Figure 2.9: An example of a 2 by 2 maxpooling operation [63]

After several layers of convolution and pooling, the feature space is flattened into 1D to be fed into fully connected layers found in traditional neural networks, in which all the outputs from the previous layer are fed into every neuron of the current layer. These layers are ultimately responsible for the classification of the image, where a softmax activation function in the final layer returns a probability distribution of the possible results. Obtaining probabilities is incredibly powerful, as any uncertain measurements can be repeated on a fresh image.

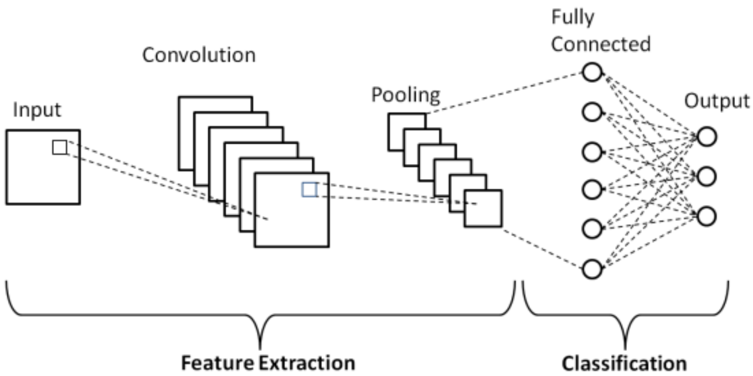

Figure 2.10: Schematic diagram of a basic CNN architecture [64]

F. Chollet describes a simple CNN architecture which achieves a 99.2% classification accuracy on the MNIST database comprised of 28 by 28 pixel binary images of handwritten digits [65]. Not only is performing OCR on printed text much easier than recognising human handwriting [66], but restricting the character class the fewer fonts further reduces the complexity of the problem [67]. Given that the tournament scrabble tiles all use the same font, this categorization problem is therefore much simpler, despite needing to classify between 27 rather than 10 characters. Although tiles which appear similar, such as 'O' and 'Q' could be problematic, the score on the bottom right corner of the tile can help disambiguate between these two. As such, should a custom CNN implementation be required for this project, a similar architecture will be considered.

2.2.4 QR Codes

QR codes are two-dimensional barcodes that store information which can be rapidly and reliably decoded in any orientation by a camera-equipped device. This provides an alternative way to encode the tile information, where a QR code could be printed on the bottom of a tile, and then captured by a camera inside the board. These codes are available in a range of sizes defined by the number of black and white squares, called modules, that make up a row, each capable of storing different amounts of data at different levels of error correction [68].

As these codes must fit on the underside of a standard scrabble tile, their total area is limited to 14mm by 14mm, meaning a trade-off between the number of modules and the module size can be made. More modules allow for more data to be encoded, which is not relevant in this application as only 2 numeric characters are required to represent all possible tile values, but also provide higher levels of error correction. On the other hand, larger modules make it easier for the QR code reader to resolve individual modules, which can help to improve the accuracy and reliability of the code reading process. The different break points for QR code size and error correction, expressed as the percentage of recoverable data bytes, for this particular application are shown in Table 2.1. QR Codes also require padding to be detected reliably. Micro QR Codes, which have symbol versions prefixed with 'M', only require 2 modules of padding, whilst standard codes require 4 modules of padding, leading to a larger step in the number of modules between these versions.

Symbol Version	Data size	Total size	Maximum Error Correction
M1	11	15	0%
M2	13	17	15%
M4	17	21	25%
1	21	29	30%

Table 2.1: QR Code error correction and size in # of modules for Scrabble tile encoding

Chapter 3

Implementation

This chapter explores the different implementations considered in addressing the requirements defined in section 1.1, with a particular focus on accurately capturing the tiles on the board and player racks, as this is the most challenging problem to overcome.

3.1 Hardware Solution

The core issue with the existing hardware implementations discussed in section 2.1 is their high cost. However, the use of an integrated hardware solution remains attractive, providing a compact and intuitive solution requiring minimal effort to set up for tournament use, and having minimal impact on the competitors. A resistive matrix approach was considered, in which the board would contain a 15 by 15 matrix with 2 exposed contact points on the edges of each square. The rows and columns on the board could be selected via a multiplexer to isolate particular squares, allowing the resistance between the contact points to be measured with a potential divider, as shown in Figure 3.1. Each tile would contain a unique resistance encoding its value, with matching contact points on its base to form a closed circuit when placed on a square. An analogue to digital (A2D) converter could then be used to pass the measured value to an embedded computer, which could then classify the tile placed.

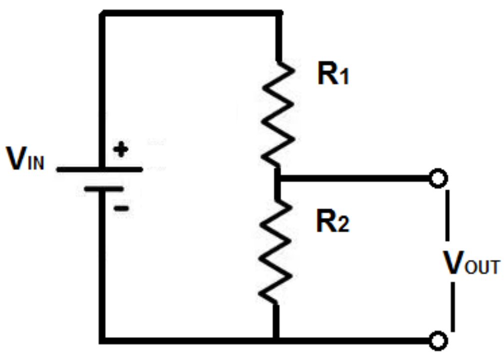

Figure 3.1: Potential divider circuit

To first determine the feasibility of such a solution, one must first verify that a wide enough range of suitable resistor values exist to encode the 27 distinct tile values. The E96 resistor range [69] was considered for this, as the low $\pm 1\%$ tolerance ensures that a high reliability can be achieved. When considering a circuit with an input voltage of $5V$ and an operating current range between $10\mu A - 10mA$, which is typical such an application, Ohm's Law provides a bound on the total resistance of the circuit of $500 \leq (R_1 + R_2) \leq 500k$. The $5V$ range can now be split into 28 intervals such that $V_{out_i} = \frac{i}{28} V_{in}$, giving a $179mV$ difference between each tile, and the corresponding resistor value for the i-th tile can be found with Equation 3.1.

$$R_i = \frac{R_1 V_{out_i}}{V_{in} - V_{out_i}} = \frac{iR_1}{28 - i} \tag{3.1}$$

Several values of R_1 were tested when generating the range of R_i values, and optimal performance was found with $R_1 = 10k\Omega$, minimising the power consumption of the voltage divider whilst keeping the total resistance within the acceptable bounds. The optimal R_i was then mapped to its closest E96 resistor, as shown in Table 3.1, such that a worst case error analysis could be performed.

i	Optimal R_i (Ω)	Closest E96 Resistor (Ω)
1	370	3.74e+02
2	769	7.68e+02
3	1200	1.21e+03
4	1667	1.65e+03
5	2174	2.15e+03
6	2727	2.74e+03
7	3333	3.32e+03
8	4000	4.02e+03
9	4737	4.75e+03
10	5556	5.62e+03
11	6471	6.49e+03
12	7500	7.5e+03
13	8667	8.66e+03
14	10000	1.0e+04
15	11538	1.15e+04
16	13333	1.33e+04
17	15455	1.54e+04
18	18000	1.82e+04
19	21111	2.1e+04
20	25000	2.49e+04
21	30000	3.01e+04
22	36667	3.65e+04
23	46000	4.64e+04
24	60000	6.04e+04
25	83333	8.25e+04
26	130000	1.3e+05
27	270000	2.67e+05

Table 3.1: Resistor values for tile encoding

By taking the maximum and minimum resistances given the $\pm1\%$ tolerance of the E96 series, the maximum and minimum voltage reading corresponding to a particular tile can be calculated. Comparing these extremes to neighbouring i values then allows the worst-case difference in voltage to be calculated, which can then be compared to the ideal $179mV$ difference between levels. For the resistor values found in Table 3.1, the average worst-case difference was $156mV$, and the smallest worst-case difference was $138mV$. The table containing the full range of values can be found in Appendix B. Compared to the $0.61mV$ quantization error of a 12-bit A2D converter, even in the worst-case scenario the resistor values should be distinct enough to identify accurately.

The results above show that provided the tiles form a strong contact with the board, tile values can be encoded in such a way that they could be easily distinguished from one another. Unfortunately, it is likely that contact resistance would have a substantial distorting effect on the actual resistance values measured by the circuit in practice for a number of reasons. Contact resistance is inversely proportional to the force applied to the contact [70]. Given that standard scrabble tiles weigh $\sim$ 1g, the force applied to the contact from the weight of the tile alone would be around $0.01N$, which is orders of magnitude lower than the $1N$ minimum commonly required for a reliable contact [71]. A solution with magnets embedded under each square on the board, with metal plates inside each tile could ensure this minimum is reached, but this would add complexity to the construction of the board and tiles, increase costs, and require the tiles to be demagnetized between rounds to avoid having them stick together. Additionally, the contacts would oxidise over time, further degrading their strength over the lifetime of the board. As such, this solution was ultimately deemed too unreliable in this application, although if methods to overcome the contact resistance issue are discovered future designs following this approach may be useful to consider.

3.2 Optical Solution

Two different optical solutions were explored, one using the existing camera setup used for live-streaming matches with OCR, and one using cameras built into the board with QR codes on the bottom of tiles.

3.2.1 Optical Character Recognition (OCR)

This solution would use the existing camera setup to capture live footage of the games, then use digital image processing and a convolutional neural network to segment the board into squares and determine the tile on a particular square. For the racks, pre-processing would be used to isolate and rotate the tiles in the correct orientation, resulting in images that can be passed into the same neural network for categorization.

Based on comparable OCR problems [65] [25], a minimum resolution of 30 by 30 pixels would be required to accurately identify a particular tile measuring 19 by 19 mm, meaning a pixel density ρ at least 1.58 pixels per millimeter (ppmm) are required. This value needs to be compared with the resolutions obtained using the current streaming setup to ensure that this approach is feasible, which can be accomplished using simple trigonometry. A visualisation of the problem is shown in Figure 3.2.

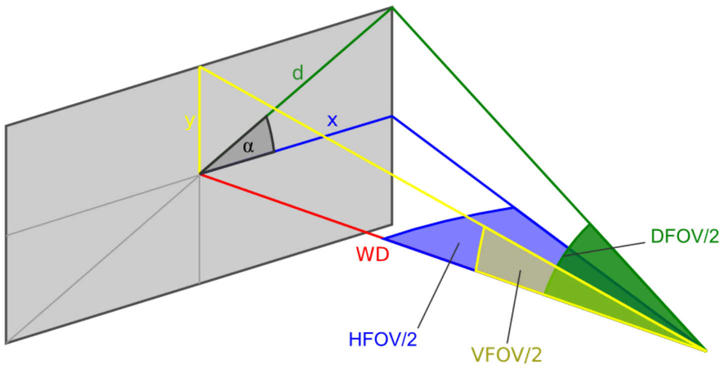

Figure 3.2: Obtaining pixel density from AFOV

Full high-definition webcams are used to capture footage, meaning that images received are 1920 by 1080 pixels, and have a standard diagonal AFOV of 78°. Using this information, the following can be derived:

$$\begin{aligned} \alpha = \arctan\left(\frac{1080}{1920}\right) \approx 29.4^\circ \qquad & d = \mathrm{WD} \cdot \tan(39^\circ) \\ x = d \cdot \cos(\alpha), \qquad & y = d \cdot \sin(\alpha) \\ \rho = \frac{1920}{x} = & \frac{1920}{\mathrm{WD} \cdot \tan(39^\circ) \cdot \cos(29.4^\circ)} \end{aligned} \tag{3.2}$$

Using Equation 3.2, the pixel density ρ can now be found as a function of the working distance (WD). Recalling the working distances of 100cm and 10cm for the board and rack respectively from subsection 2.2.1, $\rho_{\text{board}} = 2.72$ ppmm and $\rho_{\text{rack}} = 27.2$ ppmm, both providing more than sufficient resolution to detect tiles accurately.

The feature description and matching techniques described in chapter 2 can be applied to obtain a normalise image of the board, and individual square can be isolated by super-imposing a reference grid onto the board. Grid lines can also be determined with a k = 15 k-clustering algorithm as described by Hirschberg [23], although its 94% classification rate is likely to render it infeasible.

Once game squares have been isolated, there are a number of ways to determine the presence of a tile. Given that the tiles and squares have distinct colour values, as shown in Figure 3.3, a simple option would be to compute a histogram of the colour values on a given square, and compare the distance between the peaks for an empty square. Should this difference exceed some error threshold, the square can be categorized as occupied, and individual letter detection can be applied. Unfortunately, Scrabble tournament boards are not standardised, and although the sponsor has guaranteed that all the boards and tiles used in Alchemist Cup 2024 will be identical, this would make the system quite brittle and difficult to apply to other events without adjustments. Instead, a contour detection approach could be considered, where the area of the largest bounding box on the square is used to determine the presence of a tile. As the empty squares do not contain large distinct regions, especially compared to the size of the letters on the tiles, only squares containing sufficiently large contour would be categorized as occupied. Given that contour detection operates on binary images, this method would be more robust to changes in lighting or colouration, although the text on empty special squares may cause interference with the contour detection algorithm. Should this be an issue, a combined approach may be suitable, where colour histograms are used for special squares, which have standardised colours, whilst contour detection is used for the remaining area of the board.

Figure 3.3: Tournament board and tiles for Alchemist Cup 2024

The process above should produce cropped images containing tiles for categorization. If this solution were to be selected, a pre-trained OCR engine such as Tesseract, one of the market leading open-sourced engines [72] would first be tested. Although it is outperformed [66] by Google Cloud Platform's Vision OCR [73] and Amazon's Textract [74], the use of these online APIs would increase project costs, as well as increase the number of external dependencies of the system. If insufficient accuracy is obtained with these tools, a custom CNN would be developed to classify these tiles using the relevant techniques discussed in chapter 2.

To identify tiles on racks, Canny edge detection can be used to identify tile outlines, from which area computations can be performed to filter out invalid matches. If necessary, the racks can be coloured to increase contrast between themselves, the tiles and the surrounding environment, facilitating rack segmentation, and making it easier to identify the tiles in a particular frame. The contents of the tile can then be categorized using the same OCR method as tiles on the board. However, discussions with the project sponsor have revealed several issues with this approach. Some players rotate the tiles on their racks, meaning that the tile capturing process must accommodate for any orientation, as well as rectifying this orientation to perform OCR detection. As all non-blank tiles contain a numerical score in their bottom-right corner, contour detection could once again be used to ensure that the corresponding centroid is present in the appropriate location. Alternatively, if a custom CNN is used, it could also be trained to identify tiles in any orientation, although this may require a more complex architecture.

The classification of the blank tile poses a potential issue to optical recognition. In its current state, the tile does not contain any distinguishing marks, meaning that the only way it could be identified is through a colour histogram analysis. This issue was discussed with the project sponsor, who was willing to use modified blank tiles, either containing the tournament logo or a question mark character '?', both of which should produce contours which are distinct enough to be recognised optically, especially when using a custom CNN. However, these tiles would still be missing the score in the bottom-right corner meaning that they would be difficult to normalise, and the CNN would therefore need to be trained on all of its possible orientations.

This solution would also need to handle obfuscations of both the board and rack from the players, requiring logic to detect and discard images where insufficient information is visible. In the case of the board, the area of the polygon returned by the feature matching algorithm can be checked to verify that it is within acceptable limits, and only processed if it is. Regardless, the state of the board should only be finalised when a player chooses to end their turn, in which case the board should remain unobstructed, allowing a clear snapshot to be obtained. To handle the player racks, the system can track the number of tiles n that a player should have (typically 7) based on existing game state information, and does not finalise the state of a player rack until an image where n tiles are detected is obtained. Alternatively, a full rack snapshot could be obtained over a series of partial shots, where the system determines which tiles a player has in their rack over time with the appropriate logic to handle repeated letters.

3.2.2 QR Codes

QR codes provide a reliable, machine-readable way to encode tile information, but the only space available to store this data is on the underside of the tile. As such, a new board and rack needs to be designed, containing an optical system capable of detecting this information. This requires the play surface to be built of transparent or semi-transparent material, allowing a camera inside the board to see through the area of play to detect potential QR codes, which could be accomplished relatively easily using different coloured perspex sheets to replicate the patterns on a standard scrabble board. For more rapid prototyping, using a combination of a clear perspex with a printed acetate sheet will be used, allowing different colours and patterns to be experimented with easily should initial versions prove too difficult to see through.

Once an adequate material for the top of the board is selected, a key challenge with this approach is ensuring that a feasible optical system can be designed whilst minimising the thickness of the board is minimised. As per the WESPA requirements outlined in Appendix A, ideally the board should be able to rotate easily, meaning that a large box containing camera equipment would need a custom built table housing it to allow this behaviour, rendering manufacturing and tournament setup more impractical. After discussions with the project sponsor, a board depth of 10cm was chosen as an upper bound, as anything larger would have a detrimental effect on tournament players, although the sponsor. The same upper bound was used for rack depths, and larger racks would prove quite cumbersome to fit on the tables typically used for tournament play. Furthermore, should the new system obstruct a player's view of the number of tiles on the opponent's rack, the solution must provide an alternative way of making this information available to the players to comply with WESPA's guidelines.

These requirements on the depth of the board and racks essentially provide an upper bound on the working distance (WD) of the system. Recalling the FOV for the board and racks of 322mm by 322mm and 265mm by 20mm respectively, the focal length required for an optical solution can be derived using Equation 2.3 once a sensor has been selected. For this use-case, the Raspberry Pi High Quality Camera (HCQ) module [75], measuring 6.287mm by 4.712 mm, was considered, as it is a low-cost sensor which can be fit with custom lenses and can interface easily with an embedded Raspberry Pi CPU that are used extensively in both home and industrial automation applications [76]. For the board, only the vertical FOV needs to be considered, as is is identical to the horizontal FOV but with a shorter sensor length, meaning it will be the bounding constraint in the system, resulting in a focal length $f = 1.46$mm. This is an incredibly short focal length, and although lenses satisfying this requirement exist [77], they are quite rare and were unavailable for purchase at the time of this report.

The use of multiple camera modules was therefore considered as an alternative to reduce the FOV. Although the Pi only supports a single camera by default, a multi-camera module has been developed, allowing the Pi to multiplex between up to 4 cameras [78]. For the purposes of this initial analysis, only simple arrangements to split up the space keeping the camera orientation fixed were considered, as shown in Figure 3.4, leading to overlaps in tiles on inefficient use of the sensor's dimensions were considered. Should this arrangement prove ineffective in practice, further research will be conducted to determine an arrangement which takes full advantage of the sensor size to reduce the constraints on the focal length optimally. In the 4-camera arrangement, only an 8 by 8 subset of the board needs to be tracked by a single camera, reducing the FOV to 172mm by 172mm requiring a focal length $f = 2.74$mm. A 2-camera arrangement focused on a 15 by 8 subset would have an FOV of 322mm by 172mm, in which now the horizontal FOV becomes the binding constraint and requiring a focal length $f = 1.95$mm. A much wider range of lenses exist which meet both of these constraints, and a 1.7mm lens [79] was selected for prototyping, as the requirements calculated above are only approximations, which as discussed in subsection 2.2.1 are less accurate when dealing with extremely short focal lengths. Ideally this lens will allow both the 4- and 2-camera setup to be tested, as well as enabling the effects of distortion on QR code recognition to be determined experimentally, including after the appropriate corrections [31] are applied. Providing performance is adequate on a 4-camera system, the use of longer focal lenses with lower distortion [80] may prove more desirable if the corrections applied to the 1.7mm lens are not sufficient in recovering a clear picture.

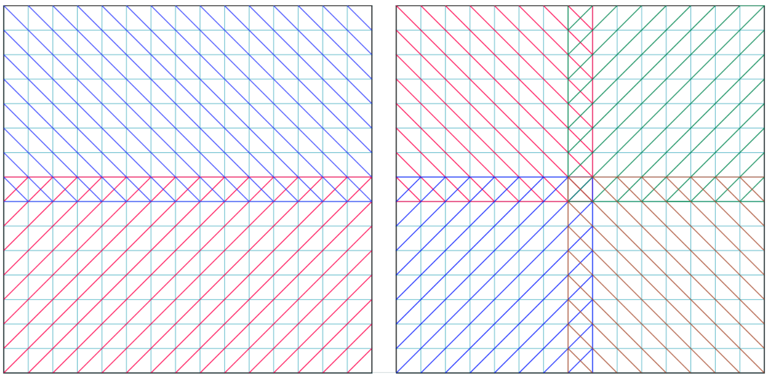

Figure 3.4: The simple 2 and 4 camera arrangements considered

In the case of the racks, assuming the standard dimensions were kept, a focal length $f = 2.37$mm is required, although given the racks only need to hold 7 tiles, each of which are approximately 19mm wide, narrower racks of 210mm would still house these comfortably and allow the focal length to increase up to $f = 3.00$mm. Discussions with the tournament sponsor confirmed that this would not be an issue for players, meaning that any lens selected for the board should be adequate for rack capture as well.

Provided a reliable optical system can be obtained, the resulting image processing problem is substantially simpler than in the OCR solution. Although standard techniques will need to be applied to ensure the solution is robust to noise, the enclosed environment provides a much higher degree of control, as LEDs inside the box can help provide constant, effective lighting.

As the cameras are inside the board, their orientation relative to the board remains constant, independent of rotations. Therefore, high-contrast etchings can be drawn on the inside of the board to substantially facilitate grid detection, simply using Canny edge detection to isolate the gridlines. A perspective transform can also be applied on the grid contour to help ensure the system is robust to slight variations in sensor placement.

Once grid squares are isolated, standard QR code detection and decoding, which has numerous open-source implementations [81] [82], can be applied to identify tiles. These detection algorithms can fail if the resolution of the QR code is too low, and initial tests of the implementations cited above revealed that a minimum of 2 pixels per module is required to detect digital QR code images. For the images captured by an optical system prone to noise, it is likely that a higher resolution will be necessary, although given the 4056 by 3040 pixel resolution of the HCQ module this is unlikely to be an issue. A 2-camera setup would have a pixel density of 12.60ppmm, resulting in 7.38 pixels per module for version 1 QR Codes, which are the largest considered for this application. As QR codes can be decoded in any orientation, and the libraries above provide capabilities to detect all QR codes in a given frame, the detection of tile in player racks should be extremely simple.

3.2.3 Comparison

Based on the analysis above, both optical solutions present a feasible solution to the problem of capturing game state data. To determine which option would be selected for this project, their performance in various parameters stemming from section 1.1 were compared. Each criteria is discussed in-depth below, and Table 3.2 summarises the conclusions drawn, with factors listed in order of importance.

Detection Accuracy

Although in theory OCR should be able to achieve an incredibly high level of accuracy with recognising tiles, this solution faces a number of challenges. Although solutions have been proposed to the blank tile and tile orientation issues, player interference with the rack cameras remains a difficult problem, and could actually make it impossible to identify the tiles a player has drawn in some games. This is an inherent limitation of the system, as instructing players to avoid fiddling with their racks would be highly detrimental to their experience, and may be ineffective as this behaviour would likely be ingrained in their play style. On the other hand, the QR code solution does not suffer from this issue, and its extensive use in part classification for manufacturing[83] proves its extremely high accuracy, and would almost certainly outperform a CNN-based classifier. The only real issue it faces in this application is if an optical system of sufficient quality is infeasible for the hard requirements on FOV and working distance. Although such a system is theoretically feasible, the calculations used are approximations, and as such the real performance of this system may differ.

System reliability and robustness to changes in environment

Image preprocessing should render both solutions quite robust to image noise and small variations in camera or board positioning. However, despite the image binarization algorithms considered, lighting could cause problems in the OCR solution, with Scorabble's main developer confirming that shadows and reflective surfaces can substantially degrade the performance of its recognition system. Given that the board surface will be somewhat transparent in the QR code solution, it may also be affected by lighting, although the use of internal lighting, as well as QR codes error correction capacity when it is partially obstructed should almost completely mitigate this. As such it is considered significantly superior to the OCR solution in this particular area.

Impact on player experience

Given that the OCR solution uses the existing camera setup used for tournament broadcasts, it would have no effect on competitors, which is ideal. Even if the QR code based solution conforms to the depth requirements, the board would still be thicker than those players are used to which may cause some visual discomfort. The text on the special squares may also have to be removed as these may interfere with QR code recognition, although this may not be an issue, as many online scrabble board do not include this text. If any changes to the board design are necessary, they will be discussed with the project sponsor to ensure that players are not affected.

Another potential issue raised by the project supervisor is that the underside of tiles will now contain a QR code identifying which tile it is. A competitor may hypothetically memorise the QR code patterns corresponding to particular letters, and could be able to determine which tiles their opponent draws if the tile underside is visible to them. Based on previous live-streamed games, this is unlikely to be an issue as players typically place their drawn tiles face-down in front of them, which is not clearly visible to their opponent. Furthermore, as per WESPA tournament rules, players may draw tiles directly onto their rack, which would avoid the problem altogether, although players may not be used to doing this. When exchanging tiles, unwanted tiles must be placed facedown on the table before being exchanged, although again these tiles can be placed in front of the player redrawing to avoid giving an opponent any information. However, should this issue still be considered a problem by the sponsor, multiple QR codes could be used to for each letter, creating an arbitrarily large state-space to encode tiles rendering memorisation infeasible.

Estimated cost

A components required for a QR code solution are as follows:

- 3 Raspberry Pis, one for the board and each rack, costing £25-£40 each depending on the compute power necessary.
- 4-6 Hich Quality Camera (HCQ) modules costing £40 each, as well as an appropriate lens costing at most £10 each.
- 1 Multi-camera adapter module costing £40 each.

The manufacturing of the board and racks themselves using perspex and acetate should be quite cheap, and would likely cost under £20, leading to total estimated costs of £335-£480 per system.

Although the OCR solution can rely on the current streaming infrastructure, in previous tournaments only one of these was necessary as multiple games could not be broadcast due to the digitization limitations. As such, should this solution be selected additional hardware will need to be purchased to replicate this setup, which according to the tournament broadcast team would be quite expensive and cost over £1000 if the same system, in which all camera feeds are processed by a single computer, is used. Wifi-enabled cameras could be used stream tournament footage to a cloud computer, which would likely reduce costs, although these would likely be equivalent or more expensive to the QR code approach.

Difficulty of production and setup

Issues with global semiconductor supply chains, largely as a result of the COVID-19 pandemic [84] has led to a shortage of Raspberry Pis available on the market, although supply is expected to return to pre-pandemic levels in Q2 of 2023 [85], meaning that acquiring the necessary components should not be an issue for Alchemist Cup 2024. However, time will need to be spent finding an appropriate manufacturer for the system itself. Although this does not fall strictly under the scope of this project, this is not expected to be a challenge as the construction of the board should be quite simple, and the expertise of college lab technicians can be relayed to the project sponsor to assist them in finding an appropriate solution. Given that the OCR solution would leverage the existing streaming setup, it would require no additional effort and would therefore be easier than the QR code solution.

Implementation difficulty

This factor needs to be considered primarily to ensure that it is feasible for the project to be completed in an appropriate time-frame. An OCR approach would require more complex preprocessing as well as CNN optimisation, both of which would be non-trivial problems requiring significant development effort. In contrast, the QR code solution should be simpler from a software side, although the optics involved are more complex, and some time would need to be spent experimentally to design an adequate system. Regardless, it is expected that sufficient time is available to complete either solution, although overall the QR code approach should take less time compared to the image processing needed for OCR, meaning that more project time will be available for other components of the system.

Parameter	OCR	QR Code
Detection accuracy	High, potential issue with racks	Extremely high
Reliability	Affected by lighting	Highly robust
Player experience	No effect	Visual discomfort
Estimated cost	>£1000	£335-£480
Setup difficulty	Replicate current setup	Requires manufacturing
Implementation difficulty	Preprocessing and CNN training	Optical system design

Table 3.2: Summarised performance of optical solutions in relevant criterion

Based on this analysis, it was concluded that the QR code solution was better suited for this project, as its superior performance in game state detection and lower costs outweighed the potential negatives from the effects on the player experience. However, this decision hinges on the feasibility of the optical system necessary, which will need to be verified experimentally before additional work is performed on this approach.

3.3 System Design

Although a solution to detecting the game state is the most challenging part of this problem, several other issues remain. Players must be able to provide input to the system to provide the value of blank tiles, as well as to indicate the end of their term, as this information is necessary to broadcast the match but cannot be determined unambiguously from the solutions described above. As such, the use of a tablet, in which a UI would be designed where this information could be provided was considered necessary. This UI could replace the digital clocks that competitors currently use to end their turns, meaning that no additional effort would be necessary from the players' behalf to capture this information, and when the board detects a blank tile in play, a prompt can be displayed requiring the user to enter this information. Obtaining data from the board also allows the UI to display the number of tiles on each players rack should the QR code solution obstruct this information, and various other useful features could be included. Scores could be automatically calculated and display, and word challenges could be handled seamlessly; a button could allow the user to select from a list of words that their opponent played in the previous turn and verified against the tournament word list, which for current WESPA tournaments is CSW21 [86].

This application would have to be implemented for iOS and Android, and although iOS is typically considered easier from both a development and maintenance perspective [87], the IDE used to write Swift, the language iOS applications are written in, is only available on MacOS [88], making it challenging to develop such applications on a Windows computer. Additionally, a typical challenge associated with Android development is the range of different screen resolutions that an application needs to accommodate [87], but for the purposes of Alchemist Cup 2024 a specific tablet model can be selected, mitigating this issue as the application would only need to consider a single resolution. Android applications can also easily be exported to a package which can be installed on the target device. This is more difficult for iOS applications, which usually need to be published on the App Store, requiring a yearly 99 USD developer fee. Android development was therefore chosen, and discussions will be held with the project sponsor to select the desired tablet this application will target for the tournament.

The information from the tablet needs to be combined with the game data captured by the smart board and racks to determine a full picture of the state of play. Although the applications could communicate with each other directly, this would mean that either the tablet application or smart board would be responsible for the logic of combining the information from both components, calculating scores, handling challenges, as well as encoding the general game logic. Ideally, the tablet application will be kept as simple as possible due to the author's lack of experience with mobile application development, making it undesirable to be used for this purpose, and the limited computational resources of the embedded Pi, already used for image processing, would likely also make it unsuitable. As such, it was determined that the use of a client-server architecture was most appropriate for this system, where both the smart board, racks and tablet would communicate via a server that would serve as the single source of truth for the system.

Information from the racks and the board can also be combined to enhance the robustness of game state detection by ensuring that new board and rack states are feasible considering their previous states. If any of the board and rack deltas fail to match between snapshots, the server could request for this information to be re-measured and transmitted, hopefully resolving the error but in the worst case alerting the broadcast team to the issue, allowing for manual intervention. To de-couple this system from the Woogles API, which would simplify testing and improve maintainability, a separate bridge component acting as an interface between the game state server and woogles would also be developed. These two components could be cheaply hosted on an AWS instance for the duration of the tournament, or on any available compute resources the project sponsor has available. A high-level diagram of the overall system is shown in Figure 3.5.

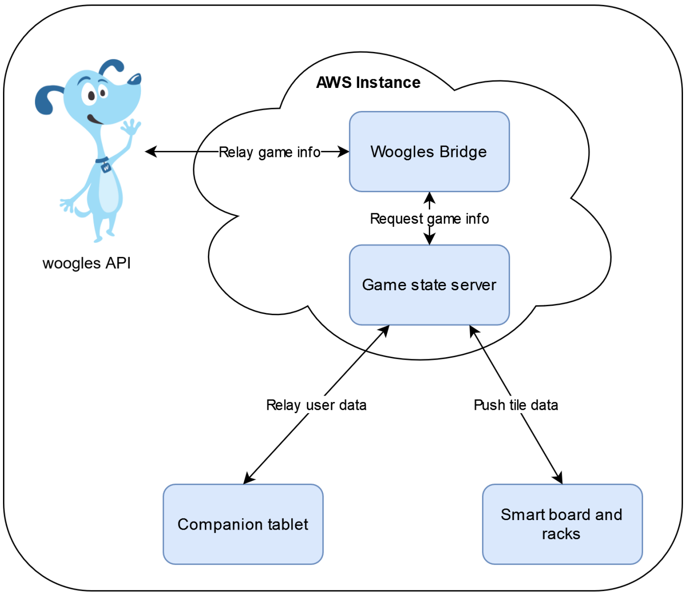

Figure 3.5: High level system architecture

3.3.1 Deliverables

Based on the system design outlined above, the core technical deliverables required for this project are summarised below:

- Hardware prototype of the smart board and racks with accompanying embedded software.
- Mobile application for tablet responsible for timekeeping and end-of-turn and blank tile capture.
- Server component responsible for resolving information from hardware and tablet components into a single, unified game-state.
- Woogles bridge component responsible for interfacing between the server and woogles API.
- Clear documentation outlining how to reproduce this setup for Alchemist Cup 2024.

3.3.2 Technology Stack

Although this project requires multiple different components, a similar technology stack should be used whenever possible to simplify development effort and facilitate future maintainability. The use of Python was considered ideal as a primary language for the development of this system; Its ease of use enables rapid development, allowing for quick prototyping and testing, and has extensive community support, with access to many libraries for image processing and computer vision, as well as web frameworks. Although it is not ideal for high performance, which may be required for embedded applications, these libraries are typically written in highly performant languages with python bindings, meaning that the bulk of the computationally intensive workload is completed efficiently.

OpenCV is a powerful, open-source, widely used computer vision library [89], providing implementations for all of the techniques discussed in chapter 2. It is written in C++, providing high levels of performance which are essential for an embedded application, and has bindings in many languages. Unfortunately, it is only capable of detecting standard QR codes, meaning that a different library would be required to decode micro-QR codes. Currently, BoofCV, a library for real-time computer vision written in Java, is the only open-source library which supports these codes [90]. Both of these libraries have bindings in Python, although BoofCV retains a dependency on the Java Virtual Machine (JVM) which could potentially cause some performance issues on a Pi. However, it will still be tested as micro-QR codes may be necessary for higher QR code resolution.

Web frameworks such as Flask [91] also enable simple server development in Python, meaning it can be used for the server and woogles bridge.

An added benefit of Python is that it is the most popular language for machine learning [92], meaning that should a switch to OCR become necessary, any existing preprocessing done with OpenCV can be kept, and powerful Python machine learning libraries for convolutional neural networks such as Keras [93] can be used. Tesseract, an open-source OCR engine which can detect any unicode character [72] also has a python wrapper allowing it to be used in conjunction with OpenCV image objects, allowing for this option to be tested easily as well.

Kotlin is a cross-platform, statically typed, general-purpose high-level programming language recommended by Google for Android application development [94], and as such will be used to develop the mobile application for the tablet.

Chapter 4

Planning

4.1 Project Plan

This project was broken down into 3 core stages, with a full project Gantt chart shown in Figure 4.1. Periods where no work is expected to take place due to holidays or exam revision are blocked out in red, and dependent workflows are done in matching colours. In Spring Term, an average of 4 working days per week are expected to be spent on the project whilst a full 5 days a week will be used in Summer, and task lengths are scaled appropriately.

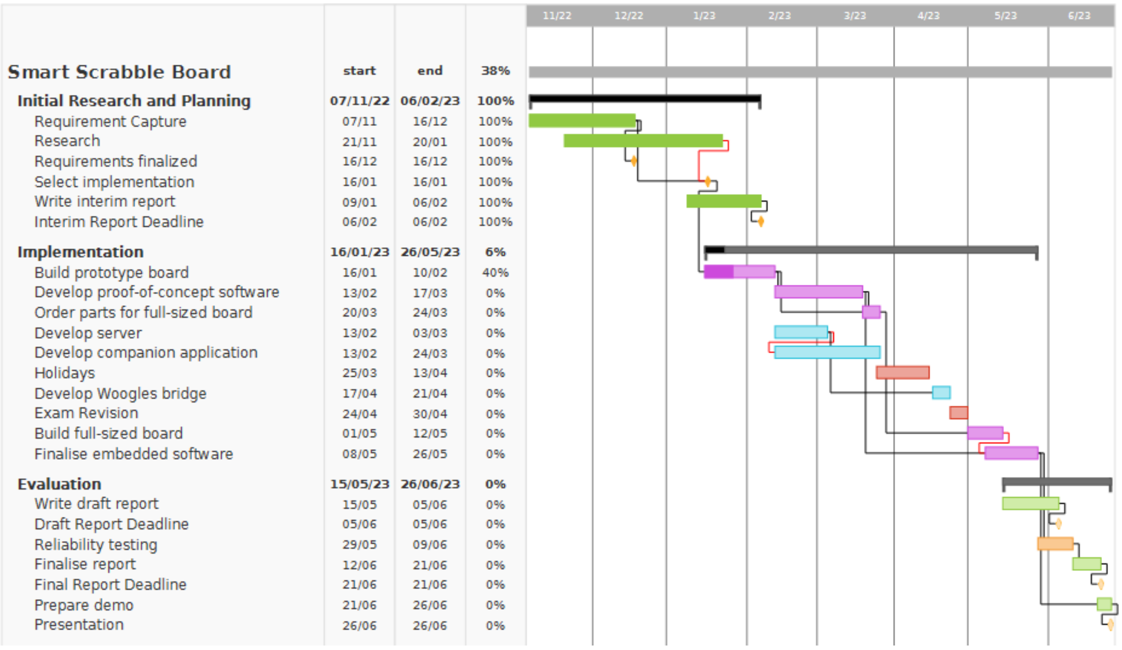

Figure 4.1: Project Gantt chart

1. *Initial research and planning*, which focused on obtaining a clear set of requirements from the project sponsor and researching potential solutions, was aimed to be completed by the end of the Autumn term to allow for implementation work to proceed smoothly in Spring, where significantly more time could be allocated to the project with respect to other university modules.

2. *Implementation* blocks out the time required to produce the core deliverables for the project, which can be split into 2 almost independent workflows of the smart board and racks themselves and the companion tablet software. Although lag time for the ordering of physical hardware is already accounted for in the Gantt chart, there is some flexibility in the way

implementation work can be completed should there be unexpected delays in delivery.

3. *Evaluation* ensures that sufficient time is allocated to assess the reliability of the system, as it is a core deliverable for this project.

4.1.1 Fallbacks and Extensions

As explained in subsection 3.2.2, the feasibility of the QR code solution is contingent on the performance of its optical system. As such, some project time is allocated to building a board prototype, in which a single camera will be tested on an 8x8 corner of the board to verify that this system works as expected. Should some insurmountable issues be encountered regarding the optics, there is sufficient project time to pivot to an OCR solution. Component delivery lag times have already been considered in the project plan, and as mentioned previously the flexibility in order of development of the different components would allow for work to be rescheduled around unforeseen delays. If more time than expected is required for implementation, which is unlikely, the development of the Woogles bridge can be shifted to be completed after the university project deadline, as although enhancing the demonstrative capabilities of the system, it is not essential, and can always be completed for the sponsor afterwards, allowing the time allocated for it to be spent on other components of the system. The sponsor also highlighted that the ability of the system to handle player challenges is a non-essential feature, as the current standard methods could continue to be used (see Appendix A for details), meaning this feature could be cut if more time is required to ensure the operation of the core game capture functionality.

Although the current scope of the project seems sufficiently ambitious, should all the required work be completed to a high degree of quality with time to spare, additional features could be implemented to facilitate the setup of the smart board to make it easier for people with less technological literacy to prepare. Although this is not necessary for the use of the board during Alchemist cup, which has a dedicated tech team, the sponsor has expressed interest in potentially mass manufacturing the board for Scrabble hobbyists should the system work well. Ensuring the board has an easy setup method would be vital in ensuring that this system is accessible to the average layperson. In general, ensuring that the system is easy to maintain and build upon would become a high priority once high confidence in its performance is achieved, as it would likely be reused in future tournaments, meaning spending time refactoring and documenting the codebase would have substantial value. Further improvements to the reliability and performance of the system could also be somewhat beneficial extensions, depending on the ease of adding such features, although it is expected that reaching the current project requirements would already provide adequate levels of performance, so these may provide minimal value.

4.2 Evaluation Plan

At its core, the most important functionality of the system is its ability to accurately capture the state of play in a Scrabble match. As such, the bulk of the evaluation for this project considers its performance in this task, with other evaluation metrics stemming from the project requirements detailed in 1.1, in order of their importance. The evaluation metrics are listed below:

1. The accuracy to which the game state is detected will be compared to both the target 99.9%, as well as existing comparable solutions.

2. The rate at which the game state is updated, and the worst case delay between the match and the digital representation will be compared to both the 1 second target and existing comparable solutions.

3. The degree of confidence to which the setup testing verifies the functionality of the system.

4. The impact on players will need to be evaluated quantitatively, and compared to the vanilla board.

5. The production costs of the setup will be compared to the £500 budget and existing comparable solutions.

6. The number and quality of non-essential or additional features, judging the extent to which they improve the player experience.

Data will need to be collected to experimentally provide accurate metrics for accuracy and reliability, time for which is allocated in the project plan. Qualitative feedback from the project sponsor will be considered, and if feasible, further feedback will be obtained from playing practice matches on the final product, with both casual and competitive users.

4.3 Ethical, Legal and Safety Plan

The most important ethical consideration in this project is to ensure that the product designed does not disadvantage any demographic of players relative to the current mode of play. This is already captured in the requirement to minimise disruptions to the player, but added consideration will be made to ensure the solution is as accessible as possible. Discussions with the project sponsor will be held to evaluate the impact on any players with disabilities, and if any concerns are identified strategies to mitigate these issues will be developed. The software developed as part of this system will be made open-source, which will allow future works to build on the results of this project, encouraging collaboration and innovation. If user data is used in the final project evaluation, it is important that the participants are made aware how their data will be used so that they may consent to this, and that any personal data stored conforms to UK GDPR regulations [95].

Given that this project aims to develop a product which can identify game pieces to be manufactured and used in an event, relevant patent laws need to be checked. Development and manufacturing would take place in the United Kingdom, and subsequently exported to Indonesia for use during the Alchemists cup, meaning that it could be liable in either country. Enforcement of patent law in Indonesia is not very frequent due to limited resources and a relatively underdeveloped intellectual property rights system [96]. Possible relevant patents include DGT's e-boards for chess, which has now expired [14], and a board game using optical pattern recognition [97] which has not yet been accepted, but neither seem applicable to any of the solutions considered in this project. Furthermore, given that this project itself is not for commercial gain, it is unlikely to meet the grounds for a lawsuit as no financial damages will be caused. Certain image processing algorithms mentioned in are also patented, meaning that although open-source implementations of these algorithms exist, the patent holder must be paid to use them legally. The SIFT feature detection algorithm patent expired in 2020 [98], meaning it can now be used freely, but the SURF feature detection algorithm currently has an active patent [99], and as such should ideally be avoided. Based on the brief investigation conducted, this project should not face any issues from a legal perspective. However, should the results of this project be desired to be manufactured commercially, a more extensive review by a patent attorney should be conducted.

As an electronic device, it is important to ensure that the solution developed is safe to use. There are a number of international organisations such as Underwriters Laboratories (UL), Conformité Européen (CE) and the International Electrotechnical Commission (IEC) which establish requirements for design, testing and certification of electronic devices to ensure they meet specific safety criteria. Although conformance to a specific standard is considered outside the scope of the project as they tend to be incredibly application specific, standard safety requirements should be met to ensure that it will not harm people using it. The Raspberry Pi camera module draws around 200-250mA, which is well above the 5 mA threshold for harmless current [100], and so care must be taken in the board assembly to ensure there are no tears in the ribbon cables between the Pi and the cameras. Furthermore, the housing of the board should be constructed in a non-conductive material to insulate any leaks from damaged electronic equipment. All Raspberry Pi hardware has undergone extensive safety and compliance testing [101], hence, provided their safety instructions are followed the assembled product should be safe to use. Appropriate safety measures will be adhered to when developing the prototype or dealing with any of the exposed electronic components.

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Appendix A

WESPA Tournament Rules

Part 1 – Equipment

1.1 Standard Rules

(a) These Rules apply in addition to the standard game rules ('Standard Rules'). The Standard Rules, which may change from time to time, are set out in Appendix 1.

(b) These Rules override the Standard Rules in the event of a discrepancy. Moreover:

  (i) games played under these Rules must be one on one, with both players keeping score; and

  (ii) games played under these Rules do not end if both players pass twice in succession.

1.2 Word Source

(a) The official word source, listed in Appendix 2, is endorsed by WESPA in consultation with the WESPA Dictionary Committee. It may change from time to time.

(b) Tournaments played under these Rules must not deviate from the official word source.

1.3 The Game Set

1.3.1 Tile Distribution

Both players must check before play that the set contains the correct number and distribution of tiles. Either player may request such a check. Once the game starts, corrections may not be made.

1.3.2 The Tiles

(a) Tiles that best achieve both tactile and visual indistinguishability are preferred.

(b) Any distinguishing marks (such as stickers) must be attached uniformly across the complete set of tiles.

(c) Sets free from tactile or visible irregularities caused by detachment from plastic moulding (especially on the top edges of tiles) are preferred.

1.3.3 The Board

Ordered by descending importance, the hierarchy of preferred attributes is:

(a) boards with edges measuring 33-35cm, which are rigid or can be made rigid for play;

(b) boards with indentations or ridges to prevent tiles from sliding;

(c) boards that do not obstruct a player's view of the opponent's rack;

(d) boards mounted on turntables that revolve with minimal disturbance to items on the playing table;

(e) boards with a non-reflective surface.

1.3.4 Other Equipment

(a) Players may use any rack they wish. However, the number of tiles on the rack must be clearly visible to the opponent.

(b) Tile bags must comfortably accommodate (simultaneously) the set of 100 tiles and a player's hand.

1.3.5 State of Equipment

All equipment in the game set must be in an acceptable state of repair. This includes:

(a) for tiles: clean, legible, not overly worn, hygienic;

(b) for boards: smoothly rotating (if applicable), free from excessively distracting background designs;

(c) for tile bags: opaque, not overly worn, of an appropriate size and design.

1.3.6 Varying the Equipment

Local exigency may at times require departure from the provisions in Rules 1.3.2-1.3.5. Tournament organisers should, however, make every effort to avoid this.

1.3.7 Disputes Over Equipment

The Tournament Director will resolve any disputes concerning equipment in the game set.

1.4 The Timer

1.4.1 Checking the Timer

Both players must check before play that the timer is set correctly and is working properly.

1.4.2 Precedence of Timers

(Note that in the list below, an 'optically passive' LCD screen is an LCD screen that does not emit light, such as the screen of a regular calculator)

If there is a choice of timers, the order of precedence is:

(a) digital timers with optically passive LCD screens with the following standard features:
  (i) countdown from the specified time limit to 00.00;
  (ii) display of overtime in minutes and seconds in a count-up fashion;
  (ii) neutralisation through the depression of a central button or designated area of the screen;

(b) smart device digital timers with a minimum diagonal screen size of 3.5 inches (89 millimetres) and sufficient power for expected use, with all the standard features above;

(c) digital timers with optically passive LCD screens capable only of counting up from 00.00 in such a way that overtime can be accurately calculated in minutes and seconds and which can be neutralised through the depression of a central button;

(d) analogue chess clocks.

- Other timing devices are not suitable but may be considered, at the discretion of the Director, if there is a shortage of suitable timers.
- In general, devices with a reputation of good reliability take precedence over those with a reputation of poor reliability.
- When smart device timers are used, it is recommended that every reasonable measure be taken to prolong battery life.
- All else being equal, a smart device with a larger screen takes precedence over one with a smaller screen.
- Any dispute over timing devices will be settled by the Director.

1.4.3 Neutralisation of the Timer

In these Rules, neutralising a timer means:

(a) for a digital timer: pressing a button or part of the screen whose purpose is to stop the countdown of both digital displays;

(b) for an analogue chess clock: depressing both clock buttons such that they are balanced and neither player's clock is ticking.

1.4.4 Use of a Timer is Mandatory

The use of a timer is mandatory for all games played under these Rules, though if there is a shortage of suitable timers, the Director will, using discretion, decide on a course of action.

1.4.5 Timer Position

The non-starting player may choose the position of the timer.

1.4.6 Malfunction of Timers

The malfunctioning timer must be stopped and the Director called. If the timer cannot be stopped or if the display has malfunctioned then both players must immediately write down their most accurate recollections of the amount of time left for each player at the moment of the malfunction. If the timer malfunctioned due to lack of power then the power source may be replaced or replenished and it may be used again. Otherwise, the timer must be removed from the competition, its owner must be notified, and it must be replaced with a suitable timer. The Director will, in conjunction with the players and, if necessary, any other observers of the game, determine as accurately as possible how much time each player had left. The Director will then assign each player the agreed remaining time on the replacement timer and the game will resume.

1.5 Written Aids

1.5.1 Score Sheets

Players may use either their own score sheets or those supplied by the tournament organisers. Score sheets may incorporate tile-tracking lists and may be double-sided.

1.5.2 Separate Tile-Tracking Lists

Players may prepare separate tile-tracking lists before a game, for use in addition to their score sheets. Such lists must not be designed as memory aids.

1.5.3 Acceptable Materials

The only visible papers allowed in the playing area are blank paper, contestant scorecards, blank and current game score sheets, tile-tracking lists, challenge slips, blank designation slips and result slips. All other papers must be kept invisible and must not be referred to during play. Records of previously played games must be stored in such a way that they are neither readable nor easily accessible (See also 1.6 Use of Electronic and Other Devices During Play).

1.5.4 Writing During the Game

There are no restrictions on what may be written on paper once the game begins.

1.6 Use of Electronic and Other Devices During Play

Apart from during adjudication of a challenge and with the exception of the timer, no electronic devices (including wearable devices) may be used by a player during play, unless for a justifiable reason related to health or simply for telling the time. Non-electronic devices that give an advantage to the user during play (such as calculating devices) are also not permitted. Prior to the start of the game and immediately after the game, electronic devices may be used in a way that does not distract other players. All electronic devices in a tournament venue must be set so that they cannot make distracting sound

Part 2 – Starting the Game

2.1 Determining Who Starts

(a) If no system to predetermine starts is in use, the players draw a tile each. The player whose tile is closest to the beginning of the alphabet, with a blank preceding an A, starts the game. In the event of a tie, each player draws again. No tiles are returned to the bag until the starter is decided. Once a starter is decided, the non-starter must return all tiles to the bag.

(b) Systems to predetermine starts must aim to ensure that all players in a tournament start approximately half their games. Such systems may include:
  (i) assignment of the start in each game by a tournament software program;
  (ii) 'self-balancing starts', in which the players compare their start/reply records before each game. If a player has hitherto started fewer games than his or her opponent, then that player starts. If the records are equal, the standard tile-drawing procedure is used.

(c) When self-balancing starts are in use, any player who knowingly misrepresents his or her start/reply record is considered to be cheating.

2.2 Starting the Timer

The timer of the player going first may be started once that player has removed a tile from the bag.

2.3 Late Arrivals

2.3.1 Duty to be Present

(a) All players must arrive by the scheduled starting time for each round.

(b) A player has officially arrived only when he or she is seated at the playing table ready to commence play immediately.

2.3.2 Both Players Absent

If neither player arrives by the scheduled starting time, the Tournament Director must:

(a) exercising due discretion, start one side of the timer to be used for the game;

(b) when the first player arrives, whether or not that player is due to play first, start the second side of the timer. The first player will be assigned the time showing on the first side of the timer;

(c) when the second player arrives, neutralise the timer. The second player will be assigned the time showing on the second side of the timer minus the time already deducted from the first player.

The game then proceeds as usual. No tiles may be drawn until both players arrive.

2.3.3 One Player Absent

If one player fails to arrive by the scheduled starting time, the Tournament Director must:

(a) exercising due discretion, start the late player's side of the timer;

(b) when the late player arrives, neutralise the timer. The player will be assigned the time showing on his or her side.

The game then proceeds as usual. No tiles may be drawn until both players arrive.

2.3.4 Optional Forfeiture due to Lateness

A late player whose timer has been started may elect to forfeit the game if his or her assigned game time, as calculated under Rule 2.3.2 or 2.3.3, is less than 15 minutes. For consequences see 2.3.6.

2.3.5 Compulsory Forfeiture due to Lateness

A player who fails to arrive before his or her assigned game time expires forfeits that game. For consequences see 2.3.6.

2.3.6 Consequences of Forfeiture due to Lateness

(a) A game forfeited under Rule 2.3.4 or 2.3.5 will count as a win for the opponent by a margin of 100 points. The Tournament Director may increase this margin if strategic lateness is suspected.

(b) A game forfeited due to lateness under Rule 2.3.4 or 2.3.5 will not count towards player ratings for the tournament.

2.4 Shuffling Tiles

Each player may shuffle the tiles within the bag before the game and while on turn. Shuffling tiles excessively and noisily, including hitting the bag on the table during shuffling, is distracting to fellow players and thus constitutes unethical behaviour (see Rule 6.3.1 (b)).

2.5 Special Needs / Disabilities

(a) Players must notify the Tournament Director, and, if relevant, the tournament organisers and venue of any special circumstances, such as physical impediments, that may affect their capacity to comply with any procedures set out in these Rules. Ideally, this notification should be done at least a week before a tournament.

(b) At the discretion of the Tournament Director, alternative procedures may be allowed or arranged to assist or accommodate players with special needs.

(c) At the discretion of the Tournament Director, a player with special needs may be awarded an amount of extra playing time, provided that this extra time will not interfere with the smooth running of the tournament, and with the proviso that the amount of time may be shortened if the tournament is so affected.

Part 3 – The Turn

3.1 Playing a Word

3.1.1 Elements of the Turn

To complete a turn by playing a word, a player must, in this order:

(a) place the tiles on the board (all blanks among said tiles must be properly declared according to rule 3.8 (Declaring a Blank), before the timer is pressed);
(b) announce the score for the turn (this may be computed aloud quietly);
(c) press the timer to start the opponent's time running;
(d) record the score for the turn and the cumulative score in the normal space on his or her score sheet;
(e) draw replacement tiles;
(f) tile track (if desired).

3.1.2 Writing Scores When No Tiles Remain in the Bag

If no tiles remain to be drawn, the writing of scores and cumulative scores is not a required element in completing a turn, so if one player wishes to confirm scores and the opponent has not recorded scores since the bag emptied, the timer may be stopped until both players agree on the scores.

3.1.3 Establishing Orientation

(a) The first play of the game determines the game's orientation with respect to the board's bonus square lettering. If this turn as played does not conform to the natural orientation of the bonus square lettering, then:
   (i) if the error is noticed by or is pointed out to the starting player before his or her turn has ended, then the starting player must correct the error on that player's own time, or;
   (ii) if the error is only noticed by the player going second after the second player’s timer has been started, then the second player may stop the timer and correct the error of orientation, after which the timer of the second player must be started by either player.

(b) If the first play of the game is misoriented but is not corrected before the end of the second move of the game, then the first play of the game determines the orientation of all plays for the rest of the game, so any plays after the first play which are misoriented relative to the first play may be challenged.

3.2 Exchanging Tiles

(For content relating to improper tile exchanges, refer to Rule 3.13.2 (Improper Tile Exchanges))

3.2.1 Elements of the Exchange

To complete a turn by exchanging tiles, a player must, in this order:

(a) check that the bag contains at least seven tiles;
(b) announce the exchange and the number of tiles to be exchanged;
(c) place the unwanted tiles face down on the table;
(d) press the timer to start the opponent's time running, after which no more unwanted tiles may be placed on the table, regardless of what the announced number of tiles to be exchanged was (note that if no tiles were placed on the table prior to pressing the timer then this constitutes a passed turn);
(e) record the exchange on the score sheet;
(f) draw the required number of replacement tiles, keeping them separate from the unwanted tiles;
(g) return the unwanted tiles to the bag;
(h) place the replacement tiles on the rack.

3.2.2 Exchange to Score Zero

An exchange of tiles scores zero points.

3.3 Passing

To complete a turn by passing, a player must, in this order:

(a) announce the pass;
(b) press the timer to start the opponent's time running;
(c) record the pass on his or her score sheet.

Note that pressing the timer so that the opponent can declare his or her blank on his or her own time does not count as a passed turn.

3.4 Significance of Pressing the Timer

3.4.1 Pressing the Timer Concludes Deliberation

(a) By pressing the timer in the course of playing a word, exchanging or passing, a player indicates a final choice of move. The move may not be changed after this act.
(b) A player may alter his or her choice of move at any point before pressing the timer.
(c) A player indicates a final choice of move only by pressing the timer, but if the player neglects to press the timer, final choice of move is indicated when the player places any part of a hand into the bag to draw tiles.
(d) By indicating a final choice of move as in (c), above, a player confers on the opponent an immediate right to challenge the turn.
(e) If the timer was pressed so that a player who just played an undeclared blank could declare the blank on that player's own time, it does not count as a passed turn.

3.4.2 Elements Overlapping with Opponent's Next Turn

(a) By pressing the timer in the course of playing a word, exchanging or passing, a player starts the opponent's next turn. Certain elements of the original turn may therefore overlap with elements of the opponent's next turn.

(b) If a player tile tracks before drawing replacement tiles, and the opponent is thereby delayed from drawing or counting tiles, the opponent may petition the Tournament Director for extra playing time.

(c) The Tournament Director will resolve any disputes concerning misordered turns. See also Rule 3.10.4 (Challenging an Improperly Ordered Turn / Timer Not Pressed After Play).

(d) Where tile drawing or tile counting by the opponent prevent the player on turn from immediately accessing the bag for the purpose of counting tiles, see 3.6.3 (Right to the Bag).

3.4.3 Unintentionally Pressing the Timer

If the timer has been pressed unintentionally, for example, when rotating the board or with a sleeve, the Tournament Director may be petitioned to nullify this action. If the petition is accepted, any time adjustments will be made at the discretion of the Tournament Director if deemed necessary. Play will then proceed as normal.

3.5 Keeping Score

(a) Until the bag is empty, both players must promptly record in the normal spaces on their score sheets both the score for each turn and the cumulative scores.

(b) Once the bag is empty, all further move scores and cumulative scores may be written after the timer is neutralised at the end of the game.

(c) Both players must verify the cumulative scores with reasonable frequency.

(d) Scoring errors may be corrected at any time prior to signing the result slip, though for correction of errors after the result slip is signed, see 5.4.1 (Result Slips Final Once Signed).

3.6 Prerogatives of the Player On Turn

3.6.1 Actions Reserved for the Player On Turn

A player may do the following things ONLY when it is his or her turn:

(a) adjust tiles on the board (errors of misorientation or imperfect placement of tiles may be pointed out to the player on turn, but may only be corrected by a player who is on turn);

(b) rotate or adjust the board; or

(c) ask to verify scores with the opponent, who must co-operate (keeping in mind that if the opponent has not written down the scores since the bag emptied, then the timer may be stopped until both players agree on the scores).

3.6.2 Actions Where the Player On Turn Has Priority

(a) The player on turn has priority for the following:

  (i) shuffling or counting the remaining tiles (see 3.6.3 Right to the Bag)

  (ii) checking the legality of an exchange.

(b) The player not on turn, if doing one of these things, must ensure that the player on turn is minimally disturbed by the act.

3.6.3 Right to the Bag

The player on turn has immediate right to the bag for the purpose of counting tiles and the opponent must promptly surrender the bag upon request, except if the opponent is still drawing tiles or if the opponent already has a hand in the bag and is busy counting tiles, in which case the player on turn may stop the timer until the bag is in the player on turn's possession, after which either player must restart the player on turn's timer.

3.7 Shuffling or Counting the Remaining Tiles

3.7.1 Procedure for Shuffling or Counting Tiles

To shuffle or count the remaining tiles, a player must, in this order:

(a) announce an intention to shuffle or count the tiles;
(b) show the opponent an empty hand (open palm with fingers stretched apart);
(c) hold the bag in a position acceptable for tile-drawing while shuffling or counting (see 3.9.1);
(d) show the opponent an empty hand after shuffling or counting.

3.7.2 Right to Object to Opponent Shuffling Tiles

A player may, only for a legitimate reason, object to the opponent shuffling or counting the remaining tiles. If this occurs, a tournament official may shuffle or count the tiles while the timer is neutralised, notifying both players of the result of the count.

3.8 Declaring a Blank

(a) Blanks must be declared preferably by circling a printed letter or else by writing a capital letter on a neutral sheet of paper, which must remain in clear view of both players for the duration of the game. If neither of the above papers are available for designation of the blank, then the timer may be stopped until one is procured. If a blank has been declared but the opponent is still not certain of the actual designation of the blank, then the opponent may stop the timer and demand that the player repeat the declaration of the blank. Neither oral declarations nor players' records on their personal papers are determinative.

(b) A player who plays a blank must declare it as in (a), above, BEFORE pressing the timer. If a player ends the turn without correctly declaring a blank, the opponent may immediately restart that player's timer and demand that the blank be properly declared. Pressing of the timer by the opponent in this instance does not count as a passed turn.

(c) If the identity of an improperly declared blank that was played on an earlier turn is disputed then the Director must be called. If the Director agrees that the improperly declared blank could have been legitimately mistaken for another letter by the opponent, then the opponent may declare the improperly declared blank to be that letter. All words formed that include this newly declared blank may be challenged.

(d) If a blank is properly declared and its identity is nonetheless disputed at any later time, the Director must be called. The Director will decide if there is a legitimate misunderstanding of the identity of the blank and may permit a move that has just been played based on a misapprehension of the blank's identity to be replayed.

3.9 Drawing Tiles

3.9.1 Bag Position

When drawing tiles, a player must:

(a) hold the tile bag so that its rim is at or above eye level;
(b) avert his or her eyes from the tile bag; and
(c) keep the tile bag in full view of the opponent.

3.9.2 Drawing Protocols

(a) Players need not draw tiles individually.
(b) Players must not put a hand containing tiles into the tile bag. All drawn tiles must be placed on the rack or the table before further tiles are drawn.
(c) Players must show an empty hand both before and after drawing.
(d) Tiles must be drawn with reasonable speed.

3.9.3 Keeping Tiles Above the Table

Players must keep all tiles above the level of the playing table at all times.

3.9.4 Improper Drawing

The Tournament Director will resolve any disputes concerning the propriety of tile drawing.

3.9.5 Overdrawing

If a player draws too many replacement tiles ('overdraws'), the timer must be neutralised and the overdraw corrected as follows:

(a) if NONE of the newly drawn tiles have touched the overdrawing player's rack then:
  (i) the overdrawing player places ONLY the newly drawn tiles face down on the table and shuffles them randomly;
  (ii) if the overdrawing player has 6 tiles on the rack, then the opponent turns <u>all</u> the newly drawn tiles face up, and proceeds to step (iv) of 3.9.5(a);
  (iii) if the overdrawing player has 5 or fewer tiles on the rack, then the opponent turns face up X+2 of the newly drawn tiles, where X is the number of OVERDRAWN tiles;
  (iv) from the face-up tiles, the opponent chooses X tiles and returns them to the bag;
  (v) all remaining tiles are returned to the overdrawing player, leaving that player with the correct number of newly drawn tiles to add to his or her rack.

(b) if AT LEAST ONE newly drawn tile has touched the overdrawing player's rack then:
  (i) the overdrawing player must place the newly drawn tiles AND all his or her other tiles face down on the table and intermix them;
  (ii) where X is the number of overdrawn tiles, the opponent turns face up X+2 tiles;
  (iii) from the face-up tiles, the opponent chooses X tiles and returns them to the bag;
  (iv) the remaining tiles are returned to the overdrawing player, leaving that player with a total of seven tiles to place on his or her rack.

The opponent has 15 seconds to correct the overdraw. If a correction has not been made, the opponent's timer is started. There is no time limit to making a correction except when it exceeds the assigned game time by 10 minutes (see 5.3.3 Overtime Leading to Forfeiture). Once a correction has been decided, the timer is neutralised, and the chosen tiles are returned to the bag. The remaining tiles are returned to the overdrawing player. Play resumes with the player on turn's clock being restarted.

3.9.6 Improperly Corrected Overdraws

If an opponent correcting an overdraw turns too many tiles face up, all exposed tiles must be replaced face down. The opponent then repeats subsection 3.9.5(a)(iii) or (b)(ii) as necessary, but may turn face up only X tiles, and must return those X tiles to the bag.

3.9.7 Duty to Disclose Overdraw

A player who becomes aware that he or she has overdrawn must disclose the overdraw. Non-disclosure is regarded as unethical behaviour (see 6.3 (Level 2 Offences)).

3.9.8 Late-Game Underdrawing

(a) This rule applies if a player underdraws, and the opponent empties the bag in his or her next draw.

(b) If the underdraw is discovered before the player completes his or her next turn, the opponent chooses and gives to the player the appropriate number of tiles from his or her rack.

(c) If the underdraw is discovered only after the player completes his or her next turn, there is neither a correction for the mistake nor a penalty.

(d) Late-game underdrawing is regarded as unethical.

3.9.9 Drawing Out Of Order

(a) If the out of order draw occurs before the opponent has had a reasonable chance to draw replacement tiles, AND leaves fewer tiles in the bag than the opponent would have rightfully drawn, then all of the player's newly drawn tiles are treated as overdrawn tiles to which the following procedure applies:
   - (i) the overdraw procedure given in Rule 3.9.5 (Overdrawing) is followed;
   - (ii) the opponent draws as many replacement tiles as are needed to complete his or her own draw;
   - (iii) any tiles remaining in the bag are replaced on the player's rack.

(b) If the out of order draw does not contravene (a), above, then:
   - (i) if any of the tiles drawn out of order have touched the rack of the overdrawing player, then the other player has been too slow to notice the out of order draw and the overdrawing player may replenish the rack without penalty.
   - (ii) If a player notices that the opponent has drawn out of order before any of the drawn tiles have touched the rack, then that player must call a halt to the out of order draw and stop the timer. The tiles drawn out of order must be shown to both players and returned to the bag, after which the correct order of drawing must be followed.

3.9.10 No Tile Drawing While Awaiting Adjudication

Players must not draw tiles while awaiting the adjudication of a challenge.

3.10 Accepting and Challenging Turns

3.10.1 Accepting the Turn

(a) Once a player presses the timer under Rule 3.1.1(c), the opponent may:
  (i) issue an immediate challenge (see Rule 3.11 (Procedures for Issuing and Adjudicating a Challenge));
  (ii) call 'hold' (see Rule 3.10.5 (Holds));
  (iii) choose to accept the turn without calling 'hold' or issuing a challenge.

(b) The opponent accepts the turn if he or she neither calls 'hold' nor issues a challenge before any replacement tile drawn by the player is added to the player's rack.
  (i) Once the tile bag is empty, and there are no further tiles to be drawn, there is no time limit with regard to a player accepting a turn and issuing a challenge. If a player goes over their assigned game time by 10 minutes, they will forfeit the game (see 5.3.3 Overtime Leading to Forfeiture).
  (ii) Where a player has 'played out' and the opponent has not, after five seconds, taken one of the three actions outlined in Rule 5.1.2 (Actions to be Taken Upon Playing Out), the opponent's timer is restarted until one of these actions is taken or they forfeit the game due to going overtime (see 5.1.3 Right to Restart the Timer and 5.3.3 Overtime Leading to Forfeiture).

(c) Accepting a turn waives the right to challenge that turn.

(d) Writing by the opponent does not affect acceptance of a turn.

3.10.2 Flash-Drawing

(a) If the player fails to record scores as required by Rule 3.1.1(d) before drawing a replacement tile, or if the player pre-writes the scores, he or she has flash-drawn. The opponent is not considered to have accepted the turn, and may challenge even after a replacement tile is drawn.

(b) Flash-drawing constitutes unethical behaviour (see Rule 6.3.1 (Definition of Unethical Behaviour)).

(c) If a turn is successfully challenged after a flash-draw, then:
  (i) if no flash-drawn tile has touched the player's rack, all flash-drawn tiles are revealed to the opponent and returned to the bag;
  (ii) if a flash-drawn tile has touched the player's rack, the player is overdrawn by the number of tiles drawn in the flash-draw, and Rule 3.9.5 (Overdrawing) applies.

3.10.3 Issuing and Adjudicating a Challenge - (see 3.11 (Procedures for Issuing and Adjudicating a Challenge))

3.10.4 Challenging an Improperly Ordered Turn / Timer Not Pressed After Play

A player who omits to press the timer while making a turn completes that turn by placing any part of a hand in the bag to draw replacement tiles. As soon as this occurs, the opponent may:

(a) compel the player to press the timer immediately, if he or she has not yet done so; and

(b) issue a challenge according to 3.11 (Procedures for Issuing and Adjudicating a Challenge).

3.10.5 Holds

(a) A player considering a challenge must call 'hold', thereby warning the opponent not to draw replacement tiles. The player may take any amount of time to accept or challenge the play after calling 'hold', provided that the amount of time taken does not cause the player to exceed his or her allotted game time by more than 10 minutes (see 5.3.3 Overtime Leading to Forfeiture).

(b) Unambiguous words such as 'accept' or 'okay' must be used to release a hold.

3.10.6 Courtesy Draws

(a) A player whose opponent has called 'hold' may, thirty seconds after pressing the timer, draw and look at replacement tiles. These tiles must be kept separately from the player's rack.

(b) If a challenge is upheld after a courtesy draw, the replacement tiles must be seen by the opponent and returned to the bag. The player is not considered to have overdrawn.

(c) If a challenge is upheld after a courtesy draw and the replacement tiles have (contrary to section (a)) been intermixed with the player's old tiles, the player is considered to have overdrawn, and Rule 3.9.5 (Overdrawing) applies.

3.10.7 Amount of Time Allowed to Challenge When a Player Has Played Out

Once a player has made a move that will end the game if left unchallenged, the opponent may take as much time as desired to challenge that move, provided that the amount of time taken does not cause the player to exceed his or her allotted game time by more than 10 minutes (see 5.3.3 Overtime Leading to Forfeiture). If the opponent does not immediately accept the 'out play' by revealing his or her unplayed tiles as per rule 5.1.2, then after 5 seconds of deliberation by the opponent, the player may restart the opponent's timer.

3.10.8 No Retraction or Concession of a Challenge

(a) A player who verbally expresses an unambiguous intention to challenge AND neutralises the timer is compelled to challenge.

(b) The challenger may change his or her mind about which word or words to challenge at any time before:

- (i) if self-adjudicating via smart device, any letter of any word to be challenged has been typed into the adjudication program;
- (ii) if self-adjudicating at an external device, the challenging player leaves the playing table;
- (iii) if runners are used, the challenge slip is handed to the runner.

(c) A player whose turn is challenged may not concede the challenge prior to adjudication.

3.10.9 Rechallenging

(a) Either player may request the re-adjudication of a challenge.

(b) If such a request is made, in the case of External Adjudication, the original adjudicator should not perform the re-adjudication.

(c) The re-adjudication is final unless it differs from the original adjudication, in which case the Tournament Director will provide a final adjudication.

3.10.10 Erroneous Challenges

If it is discovered that a word written on a challenge slip or entered into the adjudication program does not correspond to a word played on the board in the most recent turn, the challenge may be reissued (subject to 3.10.11 below).

3.10.11 Mis-adjudication of a Challenge

If a move is challenged, and the challenge is discovered to have been mis-adjudicated, the error may be corrected if and only if:

(a) no newly drawn tiles have touched the player's rack, or

(b) no retracted tiles have touched the player's rack.

Otherwise, play continues as normal and no account is taken of the error.

3.10.12 Board Control During Challenge

When the timer is neutralised pending an adjudication, the player whose turn has been challenged retains control of the board.

3.10.13 Challenge Penalties

(a) A player whose turn is successfully challenged loses that turn. The challenger may be penalised only if all challenged words are acceptable.

(b) The penalty for an unsuccessful challenge may vary from tournament to tournament. The following penalty conditions are considered standard:
- (i) five-point penalty per unsuccessfully challenged word (this is the preferred international norm);
- (ii) five-point penalty per unsuccessfully challenged turn;
- (iii) loss of turn ('double challenge').
- (iv) no penalty ('single challenge' or 'free challenge');
- (v) as in subsection (i) or (ii), but using ten point penalties.

(c) Other penalty conditions are not considered standard, and tournaments using non-standard penalty conditions may be considered non-rateable by WESPA. Examples are:
- (i) no penalty for first unsuccessful challenge, loss of turn for subsequent unsuccessful challenges ('dingle challenge');
- (ii) five-point penalty for first unsuccessful challenge, ten-point penalty for subsequent unsuccessful challenges;
- (iii) -5,-10,-20,-30 point (or similar) increasing penalties for unsuccessful challenges;
- (iv) time penalties.

3.11 Procedures for Issuing and Adjudicating a Challenge

A challenge may be adjudicated by the players themselves (Self-Adjudication) or by an external person (External Adjudication). Self-Adjudication is the preferred international norm, though players with legitimate reasons may use External Adjudication. In the case of Self-Adjudication, both players take responsibility for ensuring that the word source is correct and up to date. The Director may not forbid the use of self-adjudication via smart device and must inform participants before the start of a tournament which other method/s of adjudication will be allowed.

After adjudication by any method below, the timer may not be restarted until both players are seated, the move score has been re-announced or the tiles retracted, and the player whose timer would be running after the challenge has either: returned all face down tiles to their rack (recommended); or commenced with any writing on their scoresheet.

3.11.1 Self-Adjudication

(a) Self-Adjudication at an External Device
- (i) the challenger verbally expresses an unambiguous intention to challenge;
- (ii) the challenger neutralises the timer;
- (iii) the challenger clearly informs the opponent which word/s are being challenged;
- (iv) to minimise errors, it is advised that either player writes the word/s down on a challenge slip;
- (v) both players cover or turn the tiles on their racks face down and proceed to the adjudication device;
- (vi) the challenger types in the word/s being challenged into the adjudication program;
- (vii) the opponent verifies that the word/s are correctly typed and executes the adjudication command.

(b) Self Adjudication via Smart Device

(i) the challenger verbally expresses an unambiguous intention to challenge;
(ii) the challenger neutralises the timer;
(iii) the challenger clearly informs the opponent which word/s are being challenged;
(iv) the challenger types in the word/s being challenged into the adjudication program;
(v) the opponent verifies that the word/s are correctly typed and then gives verbal consent for the challenger to execute the adjudication command.

Note that the use of a smart device for self-adjudication must be agreed to by both players. The following requirements with regard to smart device adjudication are mandatory:

- The minimum screen size must be at least 3.5 inches (89 millimetres) measured diagonally.
- The device must be set so that it cannot make distracting sounds or vibrations.
- The device must be used in adjudication mode and may not be used in other modes.
- While in use, the screen must remain visible to both players.
- The device's adjudication program must be capable of accepting multiple words to be challenged at a time.

3.11.2 External Adjudication

(a) External Adjudication Using Runners

(i) the challenger verbally expresses an unambiguous intention to challenge;
(ii) the challenger neutralises the timer;
(iii) the challenger clearly informs the opponent which word/s are being challenged, and must record the word/s legibly on a challenge slip;
(iv) both players must cover or place face down any tiles they may have and the challenger calls for a runner;
(v) the runner takes the challenge slip to the External Adjudicator;
(vi) the External Adjudicator carefully checks the acceptability of the word/s on the challenge slip using the correct software or printed word list, then;
(vii) places a single tick on the challenge slip if all challenged words are acceptable, or a single cross if at least one is not, and returns the slip to the runner.
(viii) When multiple words are challenged, runners and adjudicators must not reveal to players the acceptability of individual words.
(ix) If docket printers are used to print the results of challenges, the printout may be returned to the players in lieu of the original challenge slip.

(b) External Adjudication via Self-Running

The procedure runs as for 3.11.2 (a) (External Adjudication Using Runners), just above, except that the challenger takes the place of the runner.

(c) External Adjudication via Tournament Director's Smart Device

(i) the challenger verbally expresses an unambiguous intention to challenge;
(ii) the challenger neutralises the timer;
(iii) the challenger clearly informs the opponent which word/s are being challenged;
(iv) the Director is called;
(v) the Director types the word/s to be challenged into the adjudication program, shows both players that the words have been typed in correctly, then, after verbal consent from the challenged player, executes the adjudication command.
(vi) the Director may choose to let the players use the Director's device themselves, in which case the procedure runs exactly as in 3.11.1(b) (Self Adjudication via Smart Device).

3.12 Correcting Errors of Misoriented or Imperfectly Placed Tiles

Once orientation of the game has been established (see 3.1.3 (Establishing Orientation)), errors of misoriented or imperfectly placed tiles may be corrected by the opponent as follows:

- (a) While the player at fault is still on turn, the opponent may not physically correct the error, but may point out the error.
- (b) If the error has not been corrected by the player at fault and that player's turn has ended, then the opponent may stop the timer and correct the error, after which either player may restart the opponent's timer.

Note that playing a tile in a misoriented position or imperfectly placing a tile is considered poor etiquette (see 6.4.1).

3.13 Illegal Moves

3.13.1 Challenging Word Placement

- (a) A player may challenge a turn on the grounds that a word has been placed illegally. Illegal word placements include, but are not limited to:
  - (i) failure to cover the centre square on the opening play;
  - (ii) placing tiles such that the tiles do not all form part of one word;
  - (iii) playing a diagonal word;
  - (iv) playing a word that extends beyond the 15x15 grid;
  - (v) playing a misoriented word after orientation has been established (see Rule 3.1.3 (Establishing Orientation)).
- (b) A player wishing to challenge an illegal word placement must neutralise the timer and call the Tournament Director to adjudicate.
- (c) There is no penalty for an unsuccessful challenge.
- (d) A player is free to refrain from challenging an illegal word placement. In the case of subsection (a)(i), above, if a player so refrains, the centre square retains its double-word-score value for subsequent turns.

3.13.2 Improper Tile Exchanges

- (a) A player wishing to challenge an improper or illegal exchange must neutralise the timer and call the Tournament Director to adjudicate.
- (b) If an exchange is announced but no number of tiles is specified and no tiles are placed on the table before the timer is pressed, then the turn counts as a pass.
- (c) There is no penalty for putting the old tiles into the bag before drawing new tiles.
- (d) If the exchanger fails to put the face-down tiles back into the bag, and any new tiles in a turn after the exchange are drawn by either player before the discovery is made, then said face-down tiles must be seen by both players before being returned to the bag.
- (e) If the number of tiles placed face down does not equal the number of tiles announced, then the number of face down tiles at the moment the exchanger presses the timer shall be exchanged.
- (f) There is no penalty for an unsuccessful challenge of a tile exchange.
- (g) A player is free to refrain from challenging an illegal exchange.
- (h) An illegal exchange may be challenged at any time before the exchange has been completed according to the steps in Rule 3.2.1 (Elements of the Exchange).
- (i) If an exchange is announced and the timer has been pressed but there are less than 7 tiles in the bag then the timer must be neutralised and the following algorithm applies:

(i) If the illegal exchange is only noticed after the non-exchanger has made an accepted move, or passed, or lost a challenge, then the player who made the illegal exchange will have 30 points deducted from that player's game score.

(ii) If NO NEWLY DRAWN TILE has touched the rack and NO ORIGINAL TILES have been placed into the bag, then the exchanger passes the turn. All newly drawn tiles must be shown to the opponent and returned to the bag, while all original tiles are returned to the exchanger's rack.

(iii) If NO NEWLY DRAWN TILE has touched the rack but AT LEAST ONE ORIGINAL TILE has been placed into the bag, then any original tiles on the table must be returned to the rack. The opponent exposes all newly drawn tiles and all tiles in the bag. Within one minute, the opponent replenishes the rack of the exchanger with a tile or tiles of the opponent's choice and the exchanger passes the turn. All remaining tiles on the table are returned to the bag.

(iv) If AT LEAST ONE NEWLY DRAWN TILE has touched the rack, but NO ORIGINAL TILES have been put into the bag, then the opponent exposes all tiles set aside to be exchanged plus all tiles from the exchanger's rack. Within one minute, the opponent chooses 7 of the aforementioned tiles to return to the exchanger's rack, and the rest are returned to the bag. The exchanger passes the turn.

(v) If AT LEAST ONE NEWLY DRAWN TILE has touched the rack and AT LEAST ONE ORIGINAL TILE has been put into the bag then the opponent exposes all tiles on the exchanger's rack, all tiles in the bag and any tiles set aside to be exchanged. From these tiles the opponent chooses 7 (within one minute) to be returned to the exchanger's rack, with the remainder being returned to the bag. The exchanger passes the turn.

3.13.3 Exchanging from Racks of Eight or More Tiles

After announcing an exchange and starting the opponent’s timer, if a player is discovered to have had a rack containing eight or more tiles, the following algorithm is to be applied:

(a) If no new tiles have been drawn, the overdraw procedure is applied and the offender loses their turn, i.e. cannot exchange.
(b) If the overdraw is discovered after any new tiles are drawn, but before any tiles have been returned to the bag: all exchanged, kept, and newly drawn tiles are combined. The overdraw procedure will then be applied (see part (b) of 3.9.5 Overdrawing).
(c) If the overdraw is discovered after any tiles have been returned to the bag: combine the originally kept tiles, the replacement tiles, any tiles not yet returned to the bag and the newly drawn tiles. The overdraw procedure will then be applied (see part (b) of 3.9.5 Overdrawing).

3.13.4 Exchanging from Racks of Six or Fewer Tiles

If a player is found to have exchanged from a rack of six tiles or fewer, one of the following steps is taken:

(a) If there would have been seven or more tiles in the bag had the exchanger held a full rack, play continues with no penalty to the exchanger.
(b) If there would have been fewer than seven tiles in the bag had the exchanger held a full rack, implement rule 3.13.2 (i) (Improper Tile Exchanges).

Part 4 – Interrupting the Game

4.1 Neutralising the Timer

The timer may be neutralised during the game for the following reasons:

(a) to issue a challenge;
(b) to resolve a scoring discrepancy;
(c) to correct an overdraw;
(d) to ascertain the game time assigned to a late player;
(e) to call the Tournament Director to resolve a problem;
(f) to deal with an unforeseen event such as a power failure or a spillage of liquid; or
(g) to follow any other procedure which requires neutralisation under these Rules.

4.2 Leaving the Playing Area

(a) Players must obtain the Tournament Director's permission to leave the playing area during a game.
(b) If permission is obtained, the Tournament Director will supervise the following procedure:
    (i) the player wishing to leave must complete a turn, except for drawing replacement tiles;
    (ii) the player may then leave the playing area;
    (iii) while the player is absent, the opponent may complete a turn, except for drawing replacement tiles.
(c) In an emergency, players may leave the playing area without obtaining permission. The opponent must alert the Tournament Director immediately if this occurs (see also 4.9 (Emergencies and Medical/Health Problems)).
(d) Supervision of players who leave the playing area is at the discretion of the Tournament Director. An opponent may request but may not compel supervision.

4.3 Tiles Discovered Out of the Bag

If any tiles (other than those properly in a player's possession) are discovered outside the bag at any time before the result slip has been signed, then:

(a) both players see the tiles;
(b) both players check to ensure that the tiles were not accidentally displaced from the board, especially from the corners and edges (once this is agreed, the board may not be subsequently corrected);
(c) the tiles are returned to the bag;
(d) any tiles removed from players' racks in the belief that the game was over are replaced; and one of the following steps is taken:
    (i) if both players have seven tiles, play resumes as usual;
    (ii) if only one player has seven tiles, that player's opponent draws from the bag; or
    (iii) if neither player has seven tiles, the players ascertain who should have drawn replacement tiles earliest, and that player draws from the bag. If only one player has tiles after this is done, the game is over and the result is recalculated as necessary. Under no circumstances may any moves be replayed.

4.4 Spilled Tiles

If tile/s are spilled from the bag during a game then the timer is neutralised, any tiles on racks are covered, and the Director is called. Players may look at spilled tiles which landed face-up, but may not touch spilled tiles before the Director rules on the spillage.

(a) Spillage in the period before and including replenishing of the rack:
- (i) this is managed by rule 3.9.5 (Overdrawing).

(b) Spillage just after the rack has been replenished:
- (i) the spilled tiles are turned face up on the table;
- (ii) the non-spiller has the <u>option</u> to <u>decline</u> to invoke the overdraw procedure in rule 3.9.5(b), if s/he believes that there is a chance that the spiller may potentially benefit from said procedure, and the Director affirms that said belief is legitimate.

(c) Spillage not related to drawing tiles, with 7 or more tiles in the bag:
- (i) this type of spillage is generally deemed to be accidental and carries no penalty; however,
- (ii) the non-spiller may petition the Director to scrutinise the circumstances of the spillage, after which management is at the discretion of the Director, with the maximum penalty being invoking the overdraw procedure in rule 3.9.5(b).

(d) Spillage not related to drawing tiles, with less than 7 tiles in the bag:
- (i) the Director places the spilled tile/s face up on the table;
- (ii) the spiller's rack tiles are placed face down on a separate part of the table and s/he shuffles them randomly;
- (iii) the non-spiller chooses two of said rack tiles, turns them face up and adds them to the spilled tile/s;
- (iv) the non-spiller chooses any two of the face-up tiles and gives them to the spiller;
- (v) the remaining tiles are returned to the bag.

4.5 Upset or Overturned Boards

The Tournament Director must be called immediately and the board and any scattered tiles must not be touched until they arrive. Any tiles knocked off a player's rack may be quickly covered or turned face down to prevent the opponent viewing them. After hearing the testimony of both players and any witnesses of the event, the Tournament Director must decide whether the board was upset accidentally or intentionally.

4.5.1 Accidental Board Upsets

If this occurred due to a table collapse, then all tables must immediately be checked for stability and correct extension of legs.

(a) If the game can be fully reconstructed from recorded plays (subject to approval by the Tournament Director to minimise any impact on tournament scheduling), this must be done and normal play resumes. If the Tournament Director rules that the game cannot be reconstructed due to time constraints, follow the procedure in 4.5.1 (b)).

(b) If the game cannot be fully reconstructed, the game will end. The final game scores will stand at the point at which the board was upset. Where the number of turns played by each player is uneven, the score for the last turn made is subtracted from the appropriate player's total score. Any disputes concerning final game scores will be resolved by the Tournament Director.

4.5.2 Intentional Board Upsets

Upsetting a board intentionally is considered a very serious offence and results in an immediate loss for the offending player. The offending player will also be ejected from the tournament. The spread for the lost game is calculated as follows:

(a) If the offending the player was not in the lead, they will lose the game by the current margin plus 100 points.
(b) If the offending player was in the lead, they will lose the game by a margin of 100 points.

4.6 Tiles Discovered In the Bag After the End of the Game

If any tiles are discovered in the bag, which the players had thought to be empty, before the result slip has been signed, then:

(a) both players see the tiles;
(b) any tiles removed from players' racks in the belief that the game was over are replaced; and
(c) the players ascertain who should have drawn replacement tiles earliest, and that player adds the tiles to his or her rack.

If both players still have tiles after this process, play resumes. If only one player has tiles, the game is over and the result recalculated as necessary. Under no circumstances may any moves be replayed.

4.7 Tiles Noticed to be Missing During Play

If a player notices that a tile has gone missing during play then the Director must be called to confirm this. If confirmed, a thorough search of the surrounding area must be performed, within reasonable limits. If the tile is found then refer to 4.3 (Tiles discovered Out of the Bag). If the tile cannot be found, the game must continue as if the tile was never in the bag, and after the game it must be ensured that the affected table has a full set of tiles for the next round.

4.8 Scope of Uninvited Intervention by the Director in a Game

(a) the Tournament Director may not intervene in the event of any mathematical error/s noticed by the Tournament Director or a third party;
(b) the Tournament Director must intervene when s/he notices cheating, but if the Tournament Director is made aware of alleged cheating by a third party, then s/he must investigate the allegation/s and take action as necessary, using discretion.
(c) The Tournament Director must intervene in any noticed error of procedure that leads to one player being unfairly affected (e.g. an error in challenging procedure).

4.9 Scope of Intervention by a Third Party in a Game

(a) a third party may not intervene DIRECTLY in an observed game in any way, including in errors of mathematics, errors of procedure and even cheating noticed by the third party;
(b) instances of cheating noticed by a third party must be reported to the Tournament Director, who must then investigate the allegation/s and take action as necessary, using discretion;
(c) errors of procedure noticed by a third party should be reported to the Tournament Director.

4.10 Emergencies and Medical/Health Problems

In the event of an emergency (whether medical or not), the affected player’s timer must be stopped and the Tournament Director must be called. The Tournament Director must quickly assess the emergency, decide on a course of action and, in order to preserve the smooth running or the tournament, immediately restart the affected player’s timer. If the affected player feels sufficiently recovered within the game time left for that player then the player may attempt to finish the game, otherwise the affected player resigns the game due to the emergency (see 5.7 Resigning).

Part 5 – Ending the Game

5.1 'Playing Out'

5.1.1 Procedure for 'Playing Out'

'Playing out' occurs when, after completing a turn, a player has no tiles remaining and no tiles remain to be drawn from the bag.

5.1.2 Actions to be Taken Upon Playing Out

A player attempting to play out must neutralise the timer, rather than starting the opponent's timer.

The opponent must then either:

(a) accept the turn by revealing his or her unplayed tiles;
(b) call 'hold'; or
(c) challenge the turn.

5.1.3 Right to Restart the Timer

(a) If a player has attempted to play out, and the opponent fails to accept the turn within approximately five seconds, then the player is entitled to restart the opponent's timer while awaiting the opponent's action.
(b) If an opponent's timer is so started, the opponent must neutralise the timer after deciding either to accept the turn or to challenge.

5.1.4 Tiles Remaining

(a) When one player has played out, then either:
  (i) his or her score is increased by twice the value of the opponent's unplayed tiles, and the opponent's score is unchanged (this is the procedure recommended by WESPA); OR
  (ii) his or her score is increased by the value of the opponent's unplayed tiles, and the opponent's score is commensurately decreased.
(b) If neither player is able to play out then refer to 5.2 (Six Consecutive Zero Scores End the Game)) just below.

5.2 Six Consecutive Zero Scores End the Game

The game ends after six consecutive turns scoring zero, resulting from any combination of passes, exchanges and successful challenges. If this occurs, each player's final score is reduced by the total value of the tiles on his or her rack.

5.3 Time Penalties

5.3.1 Ascertaining When Time Penalties Apply

A player who exceeds his or her assigned game time incurs time penalties. This occurs once:

(a) the player's timer shows -00.01 (in the case of a digital count-down timer);
(b) the player's timer shows xx.01 (in the case of a digital count-up timer, where xx represents the assigned game time in minutes); or
(c) the flag on the player's side has dropped (in the case of an analogue chess clock).

5.3.2 Application of Time Penalties

A player's score is reduced by 10 points per minute or part thereof (measured in full seconds, and NOT fractions of a second) by which he or she exceeded the assigned game time.

5.3.3 Overtime Leading to Forfeiture

A player who goes over the assigned game time by 10 minutes immediately loses the game (a forfeit loss).

Note that the NON-FORFEITER's final score remains unchanged.

To work out the score to be recorded on the result slip for the forfeiter, first deduct 100 overtime penalty points from the forfeiter's game score, and then:

(i) if, after the deduction from the forfeiter, the NON-FORFEITER has won by 100 points or more, then the forfeiter's score to be recorded on the result slip is the forfeiter's game score minus the 100 overtime penalty points;

(ii) if, after the deduction from the forfeiter, the NON-FORFEITER has NOT won by 100 points or more, then the forfeiter's score to be recorded on the result slip is calculated by deducting 100 points from the NON-FORFEITER's score.

(Note that in the unlikely event of the forfeiter's final score being a negative number after the calculations above, 100 points must be added to each player's score.)

5.3.4 No Additional Time Penalties When Timer Not Neutralised

(a) If the timer is improperly left running at the end of the game, any time penalties that accrue beyond the point at which the timer should have been neutralised are disregarded.

(b) If a player fails to neutralise the timer when playing out, the opponent is taken to neutralise the timer by revealing his or her unplayed tiles.

5.3.5 Standard Game Time

An assigned game time of 25 minutes is considered standard. Tournaments using different times may be regarded by WESPA as non-rateable.

5.4 Result Slip

5.4.1 Result Slips Final Once Signed

A game result slip signed by both players is final, and binds the players and the Tournament Director, unless:

(a) before submitting the sheet, both players agree to correct an error on it;

(b) after submitting the slip, one or both players petition the Director to correct ONLY an error where the final game scores of the winner and loser were accidentally reversed. The Tournament Director must make every reasonable effort to correct this error, but may refuse if doing so will affect the draw or the smooth running of the tournament in a way that s/he deems to be unacceptable or overly complicated. The Tournament Director must ensure that both players are made aware of the amendment to the result slip.

5.4.2 Responsibility of Winner

The winner must hand in the result slip before leaving the playing area and assist with the Tile Check (see 5.6 Tile Check).

5.5 Recounts

5.5.1 Right to Recount

Either player may request a recount at the end of a game, regardless of spread differential, and with the agreement of the Tournament Director.

5.5.2 Recount Procedure

Partial recounts are ONLY acceptable with both players' consent. If one player refuses, a game must be recounted in full, or not at all. The timer remains neutralised during a recount.

5.5.3 Surrender of Score Sheet

A recounting player may request the use of the opponent's score sheet. The opponent may object, but must, if asked, surrender the score sheet to the Tournament Director, who may use it to assist the recounting player.

5.5.4 Tournament Director's Discretion

(a) Since recounts can interfere with tournament scheduling, the Tournament Director may halt a recount if he or she believes it is frivolous or has taken an excessive time.

(b) If the Tournament Director believes that a player is frivolously recounting or deliberately slowing the progress of a recount, then he or she may direct that no changes in that player's favour be made as a result of the recount.

5.6 Tile Check

Before leaving the playing area, BOTH players must ensure that the tiles are left on the board in preferably four 5x5 grids or one 10x10 grid.

5.7 Resigning

(a) A player may not resign a game except in an emergency.

(b) A resigned game is forfeited and cannot be resumed.

(c) The game margin in a properly resigned game is the greater of the following:

   (i) 50 points,

   (ii) the non-resigning player's lead at the time of resignation plus 50 points.

(d) The Tournament Director will determine an appropriate margin for an improperly resigned game.

Part 6 - Conduct

6.1 General Conduct

6.1.1 Expected Standards

WESPA expects players to uphold high standards of both etiquette and ethics. Respectful, courteous, fair and honest play is required. Players are honour bound not to cheat.

6.1.2 Tournament Director's Powers and Responsibilities (see also 4.7 Scope of Uninvited Intervention by the Director in a Game)

(a) In disputes concerning conduct, the Tournament Director's ruling is final.
(b) The Tournament Director must give each player a fair hearing, including (where relevant) taking the testimony of witnesses.
(c) The Tournament Director must resolve factual disputes upon the balance of probabilities.
(d) The Tournament Director may take the smooth running of the tournament into consideration.
(e) In dealing with improper conduct, the Tournament Director has a wide discretion. The appropriate remedy will vary from case to case. The Tournament Director should always act with intelligence and impartiality.

6.1.3 State of Mind

Disputes concerning conduct sometimes require the Tournament Director to form a belief about a player's state of mind. Many different factors may relevantly contribute to such beliefs. Subject to Rule 6.5 (Right of Appeal), the Tournament Director is the first and final arbiter of all such questions.

6.2 Level 1 Offences (Cheating and Abusive Behaviour)

6.2.1 Definition of Cheating

Any deliberate bad-faith violation of these Rules or the Standard Rules is an act of cheating. Cheating includes, but is not limited to:
(a) collusion;
(b) concealing or palming tiles;
(c) knowingly announcing or accepting incorrect move scores or cumulative scores;
(d) knowingly misreporting game results;
(e) using marked tiles;
(f) looking inside the bag;
(g) using accomplices, objects or materials to obtain an unfair advantage;
(h) when a player knowingly misrepresents his or her start/reply record when self-balancing starts are in use.

6.2.2 Suspected Cheating

(a) Players must avoid any personal action that might incur suspicion, and draw to the attention of their opponents any such action on their part.
(b) A player who believes that an act of cheating has occurred in his or her game should call the Tournament Director.
(c) A third party who witnesses an act of suspected cheating may not intervene directly, but must report the incident to the Tournament Director

6.2.3 Definition of Abusive Behaviour

Abusive behaviour includes, but is not limited to:

(a) making unauthorised physical contact with another player or a tournament official that intimidates, threatens or harms that person;

(b) making a statement that intimidates, threatens or insults another player or a tournament official;

(c) performing any other antisocial act that intimidates, threatens, insults or harms another player or a tournament official.

6.2.4 Penalties for Cheating and Abusive Behaviour

If, at the discretion of the Tournament Director, the degree of abuse is deemed to be minor then the penalty is a stern warning and the offender must be informed that any further abusive behaviour could lead to ejection from the tournament. Otherwise, if a player is found cheating or behaving abusively:

(a) the player will be ejected from the tournament and none of the player's games will count towards ratings. Furthermore:

  (i) if the tournament is a round robin, all of the player's games will be considered void; or

  (ii) if the tournament is not a round robin, all games already played by the player will be retrospectively awarded to the opponent with a margin of 150 points (if the opponent achieved a better result, no change will be made), and the player will be moved to the bottom of the standings and treated as a bye for all further games;

(b) the player's conduct will be reported to his or her national association; and

(c) WESPA may restrict the player's participation in future tournaments.

6.3 Level 2 Offences (Unethical Behaviour)

6.3.1 Definition of Unethical Behaviour

Any act which contravenes the spirit of equitable and fair play constitutes unethical behaviour, even if it cannot be classified as a violation of these Rules or the Standard Rules. Unethical behaviour includes, but is not limited to:

(a) impairing the opponent's view of the board;

(b) shuffling tiles persistently and noisily, or otherwise manipulating the board, bag or tiles to distract the opponent;

(c) making statements capable of misleading the opponent or affecting the opponent's play;

(d) talking unnecessarily (including loud computation of the score for a move);

(e) knowingly overdrawing, underdrawing, concealing an overdraw, or drawing out of order;

(f) deliberately flash-drawing;

(g) deliberately drawing slowly, or tracking tiles before drawing, to deny the opponent access to the tile bag;

(h) issuing frivolous challenges to gain thinking time, or calling 'hold' solely to prevent the opponent from drawing;

(i) misrepresenting the number of tiles in the bag;

(j) using devices or materials to gain an unfair advantage;

(k) knowingly misrepresenting the identity of a blank;

(l) checking scores solely in order to gain thinking time or disturb the opponent, or refusing to check scores when properly requested to do so;

(m) intermixing old tiles with tiles drawn in a courtesy draw;

(n) motioning to press the timer, but refraining, in an attempt to gauge the opponent's reaction to a turn;
(o) violating self-adjudication protocols;
(p) abusing game equipment;
(q) improperly leaving the playing area during play;
(r) not notifying an opponent of a timer malfunction.

6.3.2 Behaviour Not Considered Unethical

The following acts are not generally considered unethical:
(a) exploiting an opponent's failure to press the timer at the end of a turn;
(b) playing quickly to render the opponent short of time;
(c) failing to check the opponent's calculation of a score;
(d) the use of non-verbal body language to give a particular impression (for instance, playing a word confidently in order to dissuade the opponent from challenging);
(e) failing to challenge an invalid word for strategic reasons.

6.3.3 Penalties for Unethical Behaviour

(a) A Tournament Director who finds that a player has behaved unethically may choose to deliver an official or unofficial warning, or to impose another penalty.
(b) Possible penalties for unethical behaviour include, but are not limited to:
  (i) official warning;
  (ii) reduction of margin in tournament standings;
  (iii) loss of turn, loss of time or point penalty in the game in progress;
  (iv) forfeiture of a game;
  (v) ejection from the tournament.
(c) The Tournament Director may report unethical behaviour to the national association of the player concerned, or to WESPA.

6.3.4 Privacy of Score Sheets

It is the responsibility of individual players to ensure that private material recorded on their score sheets is adequately concealed.

6.4 Level 3 Offences (Poor Etiquette)

6.4.1 Definition of Poor Etiquette

Any failure to act with due courtesy and respect towards other players and tournament officials constitutes poor etiquette. Poor etiquette includes, but is not limited to:
(a) deliberately arriving late;
(b) rotating the board for the opponent at the completion of a turn;
(c) playing tiles upside down or with imperfect placement;
(d) placing the bag out of the opponent's reach;
(e) conducting lengthy or loud post-game analyses.

6.4.2 Penalties for Poor Etiquette

In general, poor etiquette attracts no penalty beyond an unofficial warning. However, a player aggrieved by poor etiquette may call the Tournament Director, who will assess the case on its merits.

6.4.3 Observational Etiquette (see also 4.8 Scope of Intervention by a Third Party in a Game)

(a) Persons observing a game must not:
- (i) distract the players;
- (ii) audibly discuss the game;
- (iii) do anything capable of passing information about the game to the players;
- (iv) infringe the players' personal space;
- (v) continue to observe, if asked to leave by a player or the Tournament Director.

(b) The Tournament Director has general discretion to ensure that observational etiquette is maintained, including the power to impose penalties.

(c) Annotators must fully understand and comply with observational etiquette. All other annotation arrangements, including the capacity of players to refuse annotation, are matters for the tournament organisers, the Tournament Director and the players concerned.

6.5 Right of Appeal

(a) As the Tournament Director’s decision is final during a tournament (see 6.1.2 (a)), any appeal of a decision must commence after the completion of the tournament.

(b) Any parties impacted by a Tournament Director’s decision during a tournament, or by a disciplinary decision for improper conduct, has right of appeal.

(c) Any appeal must follow the correct hierarchy of channels, namely:
- (i) the first appeal must be to the appropriate local or provincial body, if any;
- (ii) the second appeal must be to the appropriate national body, if any;
- (iii) only then may the player contact the WESPA Executive Committee, who will arrange for the finding to be reviewed as below.

(d) The WESPA Executive Committee will form a committee of disinterested players to consider the appeal, which will be determined either in person or through written submissions sent by email, fax or letter. Members of the WESPA Executive Committee are not allowed to be considered as "disinterested players". The committee so formed is the sole body that will review the correctness of the finding with the purpose of providing a recommendation to be considered by the WESPA Executive Committee.

(e) If the appeal is partly or wholly upheld, the committee will recommend a course of action to the WESPA Executive Committee. This may include the amendment of tournament results. The WESPA Executive Committee will then review the report with a view to either accept (in part or in whole) or reject the recommendation.

(f) There is no further right of appeal.

Appendix 1 – Standard Rules

Note: In the event of a discrepancy between the Standard Rules and the WESPA Game Rules, the WESPA Game Rules prevail. See Rule 1.1 (Standard Rules).

EVERY WORD COUNTS!
SCRABBLE® is a word game for 2, 3 or 4 players. Play consists of forming interlocking words, crossword fashion, on the SCRABBLE® playing board, using letter tiles with various score values. The object of the game is to get the highest score. Each player competes by using their tiles in combinations and locations that take best advantage of letter values and premium squares on the board. The combined total score for a game may range from about 400 points to 800 or more, depending on the skill of the players.

CONTENTS
1 Playing Board
100 Letter Tiles
4 Tile Racks
1 Tile Bag
100 Letter tiles:

- There are 98 tiles with letters of the alphabet and two blank tiles.
- Each of the letter tiles has score values indicated by the number to the bottom right of the letter.
- The two blank tiles have no score value, and can be used as any letter desired. When it is played, the player must state what letter it represents, after which it cannot be changed for the remainder of the game.

A_{1}	9	H_{4}	2	O_{1}	8	V_{4}	2
B_{3}	2	I_{1}	9	P_{3}	2	W_{4}	2
C_{3}	2	J_{8}	1	Q_{10}	1	X_{8}	1
D_{2}	4	K_{5}	1	R_{1}	6	Y_{4}	2
E_{1}	12	L_{1}	4	S_{1}	4	Z_{10}	1
F_{4}	2	M_{3}	2	T_{1}	6	☐	2
G_{2}	3	N_{1}	6	U_{1}	4		

SET UP

- Get a pen and paper to keep score.
- Set up the board in the middle of the playing area.
- Each player takes a rack for arranging their tiles and places it in front of them.
- All the tiles are placed in the tile bag. Each player takes a tile out to find out who plays first. The player who has the tile nearest the beginning of the alphabet, with the blank preceding 'A,' plays first. The exposed tiles are put back into the bag and the bag is shaken to shuffle them.
- Each player, in turn, then draws seven new tiles and places them on their racks. Everyone is now ready to play SCRABBLE®. Play proceeds clockwise.

RULES OF PLAY

Keeping score

One player is elected as scorekeeper. They keep tally of each player's score after each turn.

Exchanging tiles

Any player may use their turn to replace any or all of the tiles in their rack. They may do so by discarding them face down, drawing the same number of new tiles, then mixing the discarded tiles with those remaining in the bag. They then await their next turn to play.

Passing (missing a turn)

Instead of placing tiles on the board, or exchanging tiles, a player may also decide to pass, whether or not they are able to make a word (or words).

However, should all players pass twice in succession, the game ends.

Placing the first word

The first player combines two or more of their tiles to form a word and places them on the board to read either across or down with one tile on the centre square (ribbon). Diagonal words are not permitted.

All tiles played in this and subsequent turns must be placed in one continuous line horizontally or vertically.

Permitted words

You may play any words listed in a standard English dictionary except those only spelt with an initial capital letter, abbreviations, prefixes and suffixes and words requiring apostrophes and hyphens. Foreign words in a standard English dictionary are considered to have been absorbed into the English language and are allowed. Prior to starting the game, all players must agree on a dictionary to be used.

Once a tile has been placed on the board, it may not be moved unless the word is successfully challenged.

Challenging words

Once a word has been played, the word may be challenged before the score is added up and the next player starts their turn. At this point only, you may consult a dictionary to check spelling or usage. If the word challenged is unacceptable, the player takes back their tiles and loses their turn.

BOARD Premium Spaces

The playing board consists of 15 x 15 squares in the playing area with grid lines to separate the squares. There are special premium squares on the board with bonus score values:

Premium Letter Squares

A light blue square doubles the score of a letter placed on it.
A dark blue square triples the score of a letter placed on it.

Premium Word Squares

A light red square doubles the score of the word.
A dark red square triples the score of the word.

If a word crosses both premium letter and word squares, all the bonus letter values are added up before the complete word score is double or tripled.

The bonus scores of the premium squares only apply to the turn in which the tiles are placed on them.

When a blank is placed on a Triple or Double Word square, the sum of the tiles in the word is doubled or tripled even though the blank itself has no score value. When it is placed on a Triple or Double Letter square, the value of the blank tile is still zero.

Scoring the first word
A player completes their turn by counting and announcing their score, which is recorded by the scorekeeper.

The score for the turn is calculated by adding up all the values of the numbers on the tiles, plus any premium values from utilising the premium squares.

Ending a turn
At the end of every turn, the player draws as many new tiles as they have played, thus always keeping seven tiles in their rack.

Added 50-point bonus
Any player who plays all seven of their tiles in a single turn scores a premium of 50 points in addition to their regular score for the turn. The 50 points are added on after doubling or tripling a word score.

Next Player's turn
The second player and then each player in turn, has the choice of exchanging tiles, passing or adding one or more tiles to those already played so as to form new words of two or more letters.

All tiles played in any one turn must be placed in one row only across or one column only down the board.

If they touch other tiles in adjacent rows, they must form complete words crossword fashion, with all such tiles.

The player gets full score for all words formed or modified by their play. Include the bonus scores of any premium squares on which they have placed the tiles.

There are five different ways that new words can be formed:
1. Adding one or more tiles to the beginning or end of a word already on the board, or to both the beginning and end of that word.
2. Placing a word at right angles to a word already on the board. The new word must use one of the letters of the word already on the board.
3. Placing a complete word parallel to a word already played so that adjoining tiles also form complete words. In this example, more than one word is formed in the same turn and each word is scored. The common letters are counted (with full premium value, when they are on premium squares) in the score for each word.
4. The new word may also add a letter to an existing word.
5. The last variation would be to "bridge" two or more letters. (This can only happen on the 4th move or later in the game.)

Sometimes a word may cross two premium word squares. The word score is doubled then re-doubled - 4 times the complete word score; or tripled and then re-tripled - 9 times the complete word score!

End of the game
The game ends when
- all the tiles have been drawn and one of the players has used all the tiles in their rack
- when all possible plays have been made
- all players have passed twice in consecutive turns

After all the scores are added up, each player's score is reduced by the sum of his unplayed tiles, and if one player has used all their tiles, their score is increased by the sum of the unplayed tiles of all the other players.

e.g. If Player one has an X and an A left on their rack at the end of the game, their score is reduced by 9 points. The player who used all their tiles adds 9 points to their score. Remember - the game can be won or lost on the last letter in the bag!

RULES CLARIFICATIONS
- If any tile touches another tile in adjacent rows, it must form part of a complete word crossword fashion, with all such tiles.
- The same word can be played more than once in a game.
- Pluralised words are allowed.
- A word can be extended on both ends within the same move e.g. TRAINER to STRAINERS.
- All tiles played in any one turn must be placed in one continuous line only, horizontally or vertically.
- Players may not add tiles to various words, or form new words in different parts of the board in the same turn.
- The bonus scores of the premium squares only apply to the turn in which the tiles are placed on them.
- When more than one word is formed in a single turn, each word is scored. The common letters are counted (with full premium value, when they are on premium squares) in the score for each word.
- If a word crosses two premium word squares, the word score is doubled and re-doubled - 4 times the complete word score; or tripled and re-tripled - 9 times the complete word score.
- When a blank is placed on a Triple or Double Word square, the sum of the tiles in the word is doubled or tripled even though the blank itself has no score value. When it is placed on a Triple or Double Letter square, the value of the blank tile is still zero.
- When one player has used all their tiles and the tile bag is empty, the game is over. In some games, no player succeeds in using all their tiles. In this case the game continues until all possible moves have been made. If a player is unable to move, they pass their turn. If all players pass twice, in consecutive turns, the game ends.
- A dictionary or word guide may not be used while a game is in progress to search for words to fit the tiles on your rack. It may only be consulted after a word has been played and challenged.

Appendix 2 – Official Word Source

From 1st July, 2019, the official word source is Collins Official SCRABBLE® Words, 5th edition, 2019.

Appendix B

Worst Case Voltage Values

The table below computes the maximum and minimum voltage values obtained from a potential divider with a $5V$ input and $R_1 = 10k\Omega$ for the maximum 1% deviations in resistor tolerance. The worst-case difference is computed as the smallest difference in voltage between i and its neighbours assuming maximum errors.

i	E96 Resistor (Ω)	Minimum voltage (V)	Maximum voltage (V)	Worst-case difference (mV)
1	3.74e+02	0.179	0.182	171
2	7.68e+02	0.353	0.360	171
3	1.21e+03	0.535	0.545	158
4	1.65e+03	0.702	0.714	158
5	2.15e+03	0.877	0.892	163
6	2.74e+03	1.067	1.084	153
7	3.32e+03	1.237	1.256	153
8	4.02e+03	1.423	1.444	155
9	4.75e+03	1.599	1.621	155
10	5.62e+03	1.787	1.810	145
11	6.49e+03	1.956	1.980	145
12	7.5e+03	2.131	2.155	151
13	8.66e+03	2.308	2.333	153
14	1e+04	2.487	2.512	149
15	1.15e+04	2.662	2.687	149
16	1.33e+04	2.842	2.866	153
17	1.54e+04	3.019	3.043	153
18	1.82e+04	3.215	3.238	138
19	2.1e+04	3.376	3.398	138
20	2.49e+04	3.557	3.577	159
21	3.01e+04	3.744	3.762	154
22	3.65e+04	3.916	3.933	154
23	4.64e+04	4.106	4.121	163
24	6.04e+04	4.284	4.296	159
25	8.25e+04	4.455	4.464	159
26	1.3e+05	4.640	4.646	172
27	2.67e+05	4.818	4.821	172

Table B.1: Deviations in voltage with ±1% resistor tolerance