Fire Signalling: the Polybius Square

1. Introduction

In this essay, I would be analysing the Polybius square used for its original purpose, visual telegraphing through the usage of fire signals. I will first begin with a brief look into the history leading to the invention of using the Polybius square, followed by how it was being used for its intended purpose. Next, a brief explanation of Polybius square in cryptography, how it had been used in modern cryptography. Lastly, I will make comparisons between the Polybius square method used in fire signalling as a medium of communication and David Crystal's (2006) seven characteristics of text and speech.

2. Pre-Polybius Square

Before the invention of the Polybius square, the ancient Greek communicated mainly through the usage of various fire signals, as it was one of the earliest and most widespread forms of communication that was able to quickly deliver messages to various locations almost instantly at the same time (Panagiotakis et al., 2013). A series of beacon towers known as *fryktories* (from *fryktos* "torch", singular *fryktoria*), were built on carefully selected mountaintops with intervisibility that allowed for sending messages through fire signals (mysifnos, n.d.; Panagiotakis et al., 2013). Polybius, a historian and statesman in ancient Greece (ca. 200-118 BCE), wrote in The Histories, "The power of acting at the right time contributes very much to the success of enterprises, and fire signals are the most efficient of all the devices which aid us to do this" (150–117/1922, p. 233). It was evident to him that there were limitations to fire signalling despite being the most efficient, whereby all the different signals were predetermined information of common occurrences, but when information of new and unforeseen circumstances that needed instant consideration needed to be sent, it was unable to be achieved with the current methods of fire signalling (Polybius, 150–117/1922). It was therefore important that ways to overcome the limitations posed from fire signalling then be created.

Attempts to remedy the limitations, such as one devised by Aeneas making use of a system that would eventually become known as hydraulic telegraphs (mysifnos, n.d.; Polybius, 150–117/1922), does not fully solve the issue of only predetermined messages could be delivered. At the same time, there could also be occurrence of human or equipment faults resulting in the wrong piece of information being transmitted.

3. Fire Signalling using the Polybius Square

An upgraded method, which Polybius claimed "devised by Cleoxenus and Democleitus and perfected by (him)self" was able to deliver "every kind of urgent messages" accurately (150–117/1922, p. 239). At each of the *fryktoria*, the torch systems were constructed with two walls, with 5 torch holders each capable of holding lit torches coated with resin or crude oil (Kotsanas Museum of Ancient Greek Technology, n.d.; mysifnos, n.d.), and a telescope with two tubes placed between the walls, as shown in **Figure 1 below** (Polybius, 150–117/1922).

Figure 1. Image of a depiction of a *fryktoria* in operation: (mysifnos, n.d.)

At any two sides of the *fryktories* which were to signal to each other, a tablet of 5 by 5 grid with the 24 Greek alphabets placed in an order previously agreed upon by the two sides, with each column and row labelled by a number to have each alphabet represent a set of two numbers, with the first being the row number and the second being of the column (Arroyo et al., 2020; Dooley, 2018; Fabien, 2020; Kondo & Mselle, 2013; Kotsanas Museum of Ancient Greek Technology, n.d.; Mollin, 2005; mysifnos, n.d.; Polybius, 150–117/1922). An example of a grid with the Greek alphabet placed in alphabetical order is shown in **Figure 2** below, in which this grid would eventually be known as the Polybius square.

	1	2	3	4	5
1	Α	Β	Γ	Δ	Ε
2	Ζ	Η	Θ	Ι	Κ
3	Λ	Μ	Ν	Ξ	Ο
4	Π	Ρ	Σ	Τ	Υ
5	Φ	Χ	Ψ	Ω	

Figure 2. Polybius square with the Greek alphabet in alphabetical order

When one of the *fryktories* has a message that was to be delivered, the signaller would raise two torches and wait until the receiving side acknowledging by reciprocating the same action (Polybius, 150–117/1922). The torches would then be lowered for the dispatcher of the message to raise torches onto the torch holders to indicate which letter the receiver should record down (Fabien, 2020; Kotsanas Museum of Ancient Greek Technology, n.d.; Mollin, 2005; mysifnos, n.d.; Polybius, 150–117/1922). The operator from the receiving side would use the telescope to determine the torches from the sending side (Kotsanas Museum of Ancient Greek Technology, n.d.; Polybius, 150–117/1922). From the receiver's point of view, the wall on the left should correspond to the row and the right to the column. With this, the process would repeat until the whole message is conveyed.

An example given by Polybius was that if the message to be sent, was "about a hundred of the soldiers have deserted to the enemy", the signaller must be able to condense the message into words with the smallest number of letters possible, the message "Cretans a hundred deserted us" could be used instead, reducing the number of letters by half (150–117/1922, p. 241). Writing down the revised message would enable the signaller to plan for the number and order of torches raised for the whole message.

In the above example, the first letter to be communicated would be 'K' *kappa*, which is on the second row and fifth column in the grid, he would then raise two torches on the right wall and five torches on the left wall. The receiving side would then note the letter down. The second letter to be communicated would be 'P' *rho*, which is on the fourth row and second column in the grid, he would raise four torches on the right wall and two on the left. The receiving side would continue noting down the letters until the end of the message (Polybius, 150–117/1922).

The method would therefore remove the limitation of the previous methods having only predetermined messages to be sent, allowing messages of any information and details to be sent, though still slightly limited in length.

4. Effects of the Polybius Square on language use in communication

The Polybius square has been regarded as one of the first substitution ciphers ever developed by converting letters into sets of two numbers (*code*: "a numerical or alphabetic codeword substituting a complete word or phrase") (Dooley, 2018; Mollin, 2005). This would allow only those who know of what method to use to convert the code back into the original message. This way of writing and decoding messages forms the basis of cryptography.

The letters of the Latin alphabet could be substituted into the square, with the letters 'I' and 'J' combined into a space to fit into the original grid, as the Greek alphabet only has 24 letters compared to 26 in the Latin alphabet used in English, as shown in **Figure 3** below (Arroyo et al., 2020; Dooley, 2018; Fabien, 2020; Kondo & Mselle, 2013; Mollin, 2005).

	1	2	3	4	5
1	A	B	C	D	E
2	F	G	H	I/J	K
3	L	M	N	O	P
4	Q	R	S	T	U
5	V	W	X	Y	Z

Figure 3. Polybius square with the English alphabet

With this in mind, if one were to want to use the Polybius square to encipher a plaintext message, it can only be in alphabets without any numerals or special symbols (Dooley, 2018; Kondo & Mselle, 2013). One of the issues would also be the lack of blank character, or word separators, that might create ambiguities on the message when decoded, such as a decoded message of "NOWIN" could either be read as "NOW IN" or "NO WIN" (Kondo & Mselle, 2013). Another issue is that the Polybius square does not have any key ("a string of characters that would determine the output of a cryptographic algorithm"), which would render the code be decoded rather quickly by unintended recipients (Kondo & Mselle, 2013).

	1	2	3	4	5
1	P	O	L	Y	B
2	I/J	U	S	A	C
3	D	E	F	G	H
4	K	M	N	Q	R
5	T	V	W	X	Z

Figure 4. Polybius square with the key "POLYBIUS"

Various ways have been used to counter some of the issues faced, such as extending the size of the grid, to 6 by 6 to allow all 26 letters used in English and the 10 decimal digits (Arroyo et al., 2020; Dooley, 2018; Fabien, 2020; Kondo & Mselle, 2013), or even up to the maximum of 9 by 9 for 81 different characters if one wants keep each code per character to a set of two single digit numbers. One can also add on layers of other ciphers to increase the difficulty of

decoding the code, as well as introduce a key that only the sender and the intended recipient(s) are aware of, such as in **Figure 4** above, where a key "POLYBIUS" is used to restructure the position of the letters on the grid (Arroyo et al., 2020; Fabien, 2020; Kondo & Mselle, 2013), such that the message "LINGUISTICS" would be 31 24 33 22 45 24 43 44 24 13 43 in the original grid and 13 21 43 34 22 21 23 51 21 25 23 in the one where the key was introduced.

Polybius' invention has been used as the premise of various ciphers throughout the years after (Mollin, 2005). One of the most well-known applications of the Polybius square is known as the knock cipher (also tap code), where the set of numbers were turned into sounds, and was used by Russian Nihilists in the 1880s to communicate with each other in prison by knocking the numbers on the walls between the cells, and subsequently prisoners-of-war during the Vietnam War (Fabien, 2020; Mollin, 2005).

5. Properties of Speech and Text of the Polybius Square in Fire Signalling

	Speech like	**Text like**
(1)	Time-bound	Space-bound
(2)	Spontaneous*	Contrived
(3)	Face-to-face*	Visually decontextualised*
(4)	Loosely structured	Elaborately structured*
(5)	Socially interactive	Factually communicative*
(6)	Immediately revisable*	Repeatedly revisable
(7)	Prosodically rich	Graphically rich

Table 1. Summary of Crystal's characteristics of speech and text (2006), with the characteristics in coloured font most applicable to using the Polybius method in fire signalling and the * asterisk denoting varying degrees of the features

Using Crystal's seven characteristics of speech and text (2006), we can analyse the various aspects of using the Polybius square in fire signalling, comparing with the features of speech and text. Below are the elaborations of **Table 1**, explaining why some characteristics are only denoted with being of varying degree and why some characteristics contain both speech and text like features while some with neither.

(1) Time bound, not space bound

The usage of fire signals meant that the sender and the recipient were only able to look at the signals when the torch was being lifted, and no imprint would be left to be seen at a later time.

It will almost always be direct between the sender of the message at one *fryktoria* and the intendent recipient at another *fryktoria*.

(2) Contrived, with some features of being spontaneous

In the case of using the Polybius square to fire signal, the sender must reword the original message to the smallest possible number of letters while retaining the meaning of the original message before the message can be slowly sent through the raising of the torches, while making sure that the remaining alphabets that they will be showing to the other side remain free of errors. However, unlike the text like characteristics of having some lag time between production and reception, the recipient at the other *fryktoria* will be able to receive and give an acknowledgement of seeing the sent alphabet almost immediately.

(3) Some degree of being face-to-face, and some degrees of visually decontextualised

With using fire signals and sending messages over a long distance, it was not possible to have any forms of extralinguistic possibilities, nor any kind of deictic expressions. However, the sender was able to only receive a limited form of feedback from the recipient via an acknowledgement of torch raising indicating the recipient has received the message and nothing else.

(4) Some degree of being elaborately structured, not loosely structured

The sender has to structure the message in a way that is concise while having the least possible number of letters, without any long clauses or sentences, fancy vocabulary or things that were rarely pronounced.

(5) Some degree of being factually communicative, not socially interactive

It was not possible to interact with the other *fryktoria* aside from sending and receiving messages and giving acknowledgements. However, as the recipient had to note down the letters that they were given by the sender, the message would be recorded down in writing at the recipient's end.

(6) Some degree of being immediately revisable, not repeatedly revisable

As the sender was sending the recipient one letter by letter, it would not be possible to withdraw a sent letter or rephrase the message without ruining the entire message, unless there was a predetermined signal to cancel the last letter, which, if exists, would not be possible for us to know. It was therefore important that the sender has to ensure that the revised message that they will be sending was right, and that no errors were to occur during the raising of the torches for the recipient to see.

(7) Neither prosodically rich nor graphically rich

Even with using the Polybius square for fire signalling, it was not possible to include any form of features available in prosodic speech, and neither had the writing at the time this system was used been graphically rich as it is today. Therefore, this medium of communication was neither prosodically nor graphically rich.

6. Conclusion

Looking past all the limitations of using the Polybius square when fire signalling, it was a truly great invention that greatly improved the speed of transmitting information across large distances, increasing the number of details and allowing of any types of messages to be able to be transmitted for the people living in that time period. This invention had not only improved the lives of those in their time, it has also helped developed many of the cryptography methods that are currently still in use today. While comparing this medium with the characteristics of speech and text by David Crystal, we can also see how far telegraphing has come from using fire signals to communicate in the ancient times, to now where there are an abundance of technology and media for us to use to communicate with others quickly and efficiently, while also seeing how a medium of communication from thousands of years ago share similarities with what we have today.

References

Arroyo, J. C. T., Dumdumaya, C. E., & Delima, A. J. P. (2020). Polybius square in cryptography: A brief review of literature. *International Journal of Advanced Trends in Computer Science and Engineering*, *9*(3), 3798–3808. https://doi.org/10.30534/ijatcse/2020/198932020

Crystal, D. (2006). *Language and the internet*. Cambridge University Press, 2nd edition.

Dooley, J. F. (2018). *History of Cryptography and Cryptanalysis: Codes, Ciphers and Their Algorithms*. Springer. http://link.springer.com/10.1007/978-3-319-90443-6

Fabien. (2020, December 14). Reconnaître/coder/décoder le carré de Polybe, ses variations et ses successeurs [Recognising/encoding/decoding the Polybius square, its variations and its successors]. *Des tours, des detours et du géocaching*. https://www.detourgeocaching.com/2020/12/14/reconnaitre-coder-decoder-le-carre-de-polybe-ses-variations-et-ses-successeurs/

Kondo, T. S., & Mselle, L. J. (2013). An Extended Version of the Polybius Cipher. *International Journal of Computer Applications*, *79*(13), 30–33. https://doi.org/10.5120/13803-1836

Kotsanas Museum of Ancient Greek Technology. (n.d.). *Telecommunication of the ancient Greeks: Fire signals and beacons*. http://kotsanas.com/gb/exh.php?exhibit=1201001

Mollin, R. (2005). *Codes: The guide to secrecy from ancient times to modern times*. Taylor & Francis Group, LLC.

mysifnos. (n.d.). Archaíoi Pýrgoi-Fryktoríes [Ancient Tower-Fryktories]. *Sifnos Island*. https://mysifnos.gr/αρχαίοι-πύργοι-φρυκτωρίες/

mysifnos. (n.d.). [Image of a depiction of a *fryktoria* in operation]. *Sifnos Island*. https://mysifnos.gr/αρχαίοι-πύργοι-φρυκτωρίες/

Panagiotakis, N., Panagiotaki, M., & Sarris, A. (2013). The Earliest Communication System in the Aegean. *Electryone*, *1*(2), 13–27.

Polybius. (1922). *The Histories, IV, Books 9-15.* (pp. 233–247). (W. R. Paton, Trans.). Harvard University Press. (Original Work Published ca. 150–117 BCE)