GRACEFUL LABELING FOR DISCONNECTED GRID RELATED GRAPHS

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Abstract: In this paper we have proved that union of three grid graphs, $U^3_{i=1}(P_n \times P_m)$ and union of finite copies of a grid graph $(P_n \times P_m)$ are graceful. We have also given two graceful labeling functions to the grid graph $(P_n \times P_m)$.

1 Introduction

We begin with a simple undirected finite graph $G = (V, E)$, with $|V| = p$ vertices and $|E| = q$ edges. For all terminology and basic we follows Harary [1]. First we shall recall some definitions which are used in this paper.

Definition 1.1: A function $f$ is called graceful labeling of a graph $G = (V, E)$ if $f : V \rightarrow \{0, 1, ..., q\}$ is injective and the induce function $f' : E \rightarrow \{1, 2, ..., q\}$ defined as $f'(e) = |f(u) - f(v)|$ is bijection every edge $e = (u, v) \in E$. A graph $G$ is called graceful graph if it admits a graceful labeling.

Definition 1.2: The Cartesian product of graphs $G$ and $H$ denoted as $G \times H$ is the graph with vertex set $V(G) \times V(H) = \{(u, v) | u \in V(G) \text{ and } v \in V(H)\}$ and vertex $(u, v)$ adjacent to another vertex $(u', v')$ if and only if either $u = u'$ and edge $(v, v') \in E(H)$ or $v = v'$ and edge $(u, u') \in E(G)$.

The Cartesian product of two paths $P_n$ and $P_m$ denoted as $(P_n \times P_m)$ is known as grid graph on $mn$ vertices.

The graceful labeling was introduced by A Rosa [2] in 1967. Acharya and Gill [3] have investigated graceful labeling for the grid graph $P_n \times P_m$, whose vertex graceful labeling we define in Theorem 2.1, where $V(P_n \times P_m) = \{u_{ij} | i = 1, 2, ..., n, j = 1, 2, ..., m\}$. Kaneria and Makadia [4] discussed gracefulness of union of two grid graphs, for this the vertex graceful labeling function we define in Theorem 2.3. In [5] Kaneria et al. investigate graceful labeling for path union of a grid graph, star of a grid graph and cycle of even copies of a grid graph. For detail survey of various graph labelings and bibliographic references one can refer Gallian [6]. Labelled have many diversified applications.

In this paper we get graceful labeling pattern for union of finite copies of a grid graph and union of three grid graphs. Following labeling pattern for a grid graph $(P_n \times P_m)$ is graceful, but it may not help to prove union of grid graphs is also graceful.

$$f: V(P_n \times P_m) \rightarrow \{0, 1, ..., q\}, \text{ where } q = 2mn - (m + n)$$

define by

$$f(u_{i,1}) = q - \left\lfloor \frac{i-1}{2} \right\rfloor \text{ when } i \text{ is odd, } f(u_{i,2}) = \frac{i-2}{2} \text{ when } i \text{ is even, } \forall i = 1, 2, ..., n;$$

$$f(u_{i,3}) = (n - 1) + \left\lfloor \frac{i-1}{2} \right\rfloor \text{ , when } i \text{ is odd, }$$

$$f(u_{i,j}) = (q - n + 1) - \left\lfloor \frac{j-1}{2} \right\rfloor \text{ when } i \text{ is even, } \forall i = 1, 2, ..., n;$$

$$f(u_{i,j}) = f(u_{i,j-2}) - (2n - 1), \text{ when } f(u_{i,j-2}) > \frac{q}{2},$$
\[ f(u_{i,j}) = f(u_{i,j-2}) + (2n-1), \quad \text{when } f(u_{i,j-2}) < \frac{q}{2}, \]
\[ \forall i = 1,2,\ldots,n; \quad \forall j = 3,4,\ldots,m; \]

2 Main Results:

Theorem−2.1: Union of finite copies of a grid graph is graceful.

Proof: Let \( u_{i,j,k} \) (\( 1 \leq j \leq n, 1 \leq k \leq m \)) be vertices of a grid graph \( P_n \times P_m \). Let \( G \) be a finite union of \( t \) copies of the grid graph \( P_n \times P_m \). Let \( u_{i,j,k} \) (\( 1 \leq j \leq n, 1 \leq k \leq m \)) be vertices of \( i \)th copy \((P_n \times P_m)^{(j)}\) of the grid graph in \( G \), \( \forall i = 1,2,\ldots,t \)

We know that the grid graph \((P_n \times P_m)^{(1)}\) (where \( n \leq m \)) is a graceful graph on \( p = mn \) vertices and \( q = 2mn - (m + n) \) edges with following vertex labeling function.

\[ f: V((P_n \times P_m)^{(1)}) \rightarrow \{0,1,\ldots,q\} \]

\[ f(u_{1,j,1}) = \left\lfloor \frac{j-1}{2} \right\rfloor \text{when } j \text{ is odd} \]
\[ f(u_{1,j,m}) = \left\lfloor \frac{j-1}{2} \right\rfloor + \frac{1}{4} \left[ \frac{(n-1)^2}{2} + 1 \right], \quad \forall j = n, n-1, \ldots, 1; \]

\[ f(u_{1,j,k}) = f(u_{1,j-1,k+1}) + (-1)^{j+k}, \quad \forall k = m-1, m-2, \ldots, m+1-m; \]

\[ f(u_{1,n,k}) = f(u_{1,n-1,k}) + (-1)^{n-1} \left[ \frac{(2n-1)(k-1)}{2} \right], \quad \text{when } k \text{ is odd,} \]
\[ f(u_{1,n,k}) = f(u_{1,n-1,k}) - (-1)^{n-1} \left[ \frac{(2n-1)(k-1)}{2} - 1 \right], \quad \text{when } k \text{ is even,} \]
\[ f(u_{1,j,k}) = f(u_{1,j+1,k-1}) - (-1)^{j+k}, \quad \forall k = 2,3,\ldots, m-n; \]

In graph \( G \) it is obvious that the number of vertices \( |V(G)| = P = mn \) and the edges \( |E(G)| = Q =tq \). To define a labeling function \( g: V(G) \rightarrow \{0,1,\ldots,Q\} \), we shall have following two cases.

Case−I: \( q \) is even

\[ g(u_{1,j,k}) = f(u_{1,j,k}) + (Q-q), \quad \text{when } f(u_{1,j,k}) \geq \frac{q}{2} \]
\[ = f(u_{1,j,k}), \quad \text{when } f(u_{1,j,k}) < \frac{q}{2}, \]
\[ \forall j = 1,2,\ldots,n; \quad \forall k = 1,2,\ldots,m; \]

\[ g(u_{i,j,k}) = g(u_{i-1,j,k}) - \frac{q}{2} + 1, \quad \text{when } g(u_{i-1,j,k}) > \frac{q}{2} \]
\[ = g(u_{i-1,j,k}) + \frac{q}{2} + 1, \quad \text{when } g(u_{i-1,j,k}) < \frac{q}{2}, \]
\[ \forall i = 2,3,\ldots,t; \quad \forall j = 1,2,\ldots,n; \quad \forall k = 1,2,\ldots,m; \]

Case−II: \( q \) is odd

\[ g(u_{1,j,k}) = f(u_{1,j,k}) + (Q-q), \quad \text{when } f(u_{1,j,k}) > \frac{q}{2} \]
\[ = f(u_{1,j,k}), \quad \text{when } f(u_{1,j,k}) < \frac{q}{2}, \]
\[ \forall j = 1,2,\ldots,n; \quad \forall k = 1,2,\ldots,m; \]
Above labeling pattern give rise a graceful labeling to given graph \( G = \text{union of } t \text{ copies of a grid graph } P_n \times P_m \) when

\[
\forall j = 1, 2, \ldots, n, \quad \forall k = 1, 2, \ldots, m; \\
g(u_{i,j,k}) = g(u_{i-2,j,k}) - q, \quad \text{when } g(u_{i-2,j,k}) > \frac{q}{2} \\
g(u_{i,j,k}) = g(u_{i-2,j,k}) + q, \quad \text{when } g(u_{i-2,j,k}) \leq \frac{q}{2},
\]

\( \forall i = 3, 4, \ldots, t, \quad \forall j = 1, 2, \ldots, n, \quad \forall k = 1, 2, \ldots, m. \)

Above labeling pattern give rise a graceful labeling to given graph \( G = \text{union of } t \text{ copies of a grid graph } P_n \times P_m \) and so it is a graceful graph.

**Illustration**—2.2: \( U^4_{i=1}(P_3 \times P_4) \) and its graceful labeling shown in figure—1

\[
\begin{align*}
&\begin{array}{c}
\begin{array}{c}
68 \quad 1 \quad 64 \quad 6 \quad 0 \\
66 \quad 4 \quad 61 \quad 8 \\
17 \quad 49 \\
51 \quad 18 \quad 47 \quad 23 \\
41 \quad 24 \quad 40 \quad 28 \\
26 \quad 36 \quad 32 \quad 31 \quad 33 \\
57 \quad 11 \quad 53 \quad 15 \\
52 \quad 9 \quad 54 \quad 14 \\
7 \quad 10 
\end{array}
\end{array}
\end{align*}
\]

Figure 1 Disconnected graph \( U^4_{i=1}(P_3 \times P_4) \) and its graceful labeling.

**Theorem**—2.3: \( U^3_{i=1}(P_{n_1} \times P_{m_1}) \) is graceful.

**Proof:** Let \( u^{(i)}_{i,j} \) be vertices of the grid graph \( P_{n_1} \times P_{m_1} \), \( \forall i = 1, 2, 3 \).

It is obvious that the number of vertices \( p_l = |V(P_{n_l} \times P_{m_l})| \) for each grid is \( n_l m_l \) and the number of edges \( q_l = |E(P_{n_l} \times P_{m_l})| \) for each grid is \( 2mnl - (m_l + n_l) \), \( \forall l = 1, 2, 3 \).

We know that these grid graphs \( P_{n_l} \times P_{m_l} \) are graceful graphs as we mentioned its graceful labeling in **Theorem**—2.1, \( \forall l = 1, 2, 3 \). Let \( f_l : V(P_{n_l} \times P_{m_l}) \rightarrow \{0, 1, \ldots, q_l\} \) be a graceful labeling for grid graph \( P_{n_l} \times P_{m_l} \), \( \forall l = 1, 2, 3 \).

First we shall prove that \( P_{n_1} \times P_{m_1} \cup P_{n_2} \times P_{m_2} \) is a graceful graph. We define a labeling function \( f : V(P_{n_1} \times P_{m_1} \cup P_{n_2} \times P_{m_2}) \rightarrow \{0, 1, \ldots, q_1 + q_2\} \) as follows.

\[
f(u^{(i)}_{i,j}) = f_1(u^{(i)}_{i,j}), \quad \text{when } f_1(u^{(i)}_{i,j}) < \frac{q_1}{2} \\
= f_1(u^{(i)}_{i,j}) + q_2, \quad \text{when } f_1(u^{(i)}_{i,j}) \geq \frac{q_1}{2}
\]

\( \forall i = 1, 2, \ldots, n_1, \quad \forall j = 1, 2, \ldots, m_1 \);
\[ f(u_{ij}^{(2)}) = f_2(u_{ij}^{(2)}) + \frac{q_1 + q_2}{2} \]

when \( q_1 \equiv 0 \pmod{2} \)

\[ = q_1 + q_2 - f_2(u_{ij}^{(2)}) - \frac{q_3 + q_2}{2} \]

when \( q_1 \equiv 1 \pmod{2} \),

\[ \forall \; i = 1, 2, \ldots, n_2, \quad \forall \; j = 1, 2, \ldots, m_2. \]

Above labeling pattern give rise graceful labeling to the graph \( P_{n_1} \times P_{m_1} \cup P_{n_2} \times P_{m_2} \). [Above result was proved by Kaneria and Makadia [4].]

Since \( q_1, q_2, q_3 \in \mathbb{N} \) (one of three cases must be hold) either \( q_1 + q_2 \equiv 0 \pmod{2} \) or \( q_1 + q_3 \equiv 0 \pmod{2} \) or \( q_2 + q_3 \equiv 0 \pmod{2} \). Without loss of generality we may assume that \( q_1 + q_2 \equiv 0 \pmod{2} \). To define a labeling function \( g : V \left( \bigcup_{i=1}^{3} (P_{n_i} \times P_{m_i}) \right) \rightarrow \{0, 1, \ldots, Q\} \), where \( Q = q_1 + q_2 + q_3 \), we shall have following two cases.

Case–I : \( q_1 \equiv 1 \pmod{2} \) and \( q_2 \equiv 1 \pmod{2} \)

\[ g(u_{ij}^{(0)}) = g(u_{ij}^{(1)}) \quad \text{when} \quad f(u_{ij}^{(0)}) < \frac{q_1 + q_2 - 2}{2} \]

\[ = f(u_{ij}^{(0)}) + q_3 \quad \text{when} \quad f(u_{ij}^{(0)}) \geq \frac{q_1 + q_2 - 2}{2} \]

\[ \forall \; i = 1, 2, \ldots, n_1, \quad \forall \; j = 1, 2, \ldots, m_1 ; \]

\[ g(u_{ij}^{(3)}) = g(u_{ij}^{(3)}) \quad \forall \; i = 1, 2, \ldots, n_3, \quad \forall \; j = 1, 2, \ldots, m_3. \]

Case–II : \( q_1 \equiv 0 \pmod{2} \) and \( q_2 \equiv 0 \pmod{2} \)

\[ g(u_{ij}^{(0)}) = g(u_{ij}^{(1)}) \quad \text{when} \quad f(u_{ij}^{(0)}) < \frac{q_1}{2} \]

\[ = f(u_{ij}^{(0)}) + q_2 \quad \text{when} \quad f(u_{ij}^{(0)}) \geq \frac{q_1}{2} \]

\[ \forall \; i = 1, 2, \ldots, n_1, \quad \forall \; j = 1, 2, \ldots, m_1 ; \]

\[ g(u_{ij}^{(2)}) = g(u_{ij}^{(2)}) \quad \text{when} \quad f(u_{ij}^{(2)}) < \frac{q_2}{2} \]

\[ = f(u_{ij}^{(2)}) + q_3 \quad \text{when} \quad f(u_{ij}^{(2)}) \geq \frac{q_2}{2} \]

\[ \forall \; i = 1, 2, \ldots, n_2, \quad \forall \; j = 1, 2, \ldots, m_2 ; \]

\[ g(u_{ij}^{(3)}) = g(u_{ij}^{(3)}) \quad \forall \; i = 1, 2, \ldots, n_3, \quad \forall \; j = 1, 2, \ldots, m_3. \]

Above labeling pattern give rise a graceful labeling to given graph \( \bigcup_{i=1}^{3} (P_{n_i} \times P_{m_i}) \) and so it is a graceful graph.

Illustration–2.4 : \( P_3 \times P_3 \cup P_3 \times P_5 \cup P_2 \times P_4 \) and its graceful labeling shown in figure–4. While figure–2 shown graceful labeling of graphs \( P_3 \times P_3, P_3 \times P_5, P_2 \times P_4 \) and figure–3 shows graceful labeling for \( P_3 \times P_3 \cup P_3 \times P_5 \). Here \( q_1 = 12, \quad q_2 = 22, \quad q_3 = 10 \) and \( q = q_1 + q_2 + q_3 = 44 \).
3 Concluding Remarks:

We have discussed two distinct graceful labeling patterns by suitable function for a grid graph. We also proved union of finite copies of a grid graph and union of three grid graphs are graceful. The labeling pattern is demonstrated by means of illustrations, which provide better understanding of derived results. We raise open question to get graceful labeling for the disconnected graph $U_{i=1}^{t} (P_n \times P_m)$ where $t \geq 4$. 

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**Figure 2** Graceful labeling for $P_3 \times P_3$, $P_3 \times P_5$ and $P_2 \times P_4$ under functions $f_1, f_2, f_3$ respectively.

**Figure 3** Disconnected graph $P_3 \times P_3 \cup P_3 \times P_5$ and its graceful labeling under $f$.

**Figure 4** Disconnected graph $P_3 \times P_3 \cup P_3 \times P_5 \cup P_2 \times P_4$ and its graceful labeling.
References


