Can Robots Inform a Honeybee Colony's Foraging Decision-Making?

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Abstract

We used a model of honeybees' decision-making to investigate the effect of robots on the hive's foraging decisions. We find that at least two robots are needed to make a significant impact.

Introduction

Technological progress of our society often harms our climate, our agriculture, and our landscapes in multiple ways. Each of these stressors has a major negative influence on the diversity and population sizes of wild organisms. In particular the loss of pollinators is alarming, as they play a central role in ecosystems. Among those, honeybees are economically one of the most important, but endangered group (Paudel et al., 2015). Out of 100 crop species that provide the majority of the world's food, over 70 are pollinated by bees (van der Sluijs and Vaage, 2016). In short, without honeybees our food spectrum will shrink significantly. However, modern technology can also help to protect honeybees. Honeybees can determine the most profitable food source from a wide array of options and adjust their choices quickly when triggered by environmental changes (Seeley et al., 1991). Their collective foraging decisions are based on individual worker assessment of energetic net gains of food sources, advertisement of good sources via waggle dances and they also reflect the colony's nectar need (Seeley, 1994). This distributed mechanism is a fascinating example of natural swarm intelligence. Robots that mimic honeybees can convey food source information via artificial dances to living bees (Landgraf et al., 2012). They could prevent bees from foraging at attractive but potentially harmful sites (e.g., crops after spraying pesticides). However, it is unclear how many individual decisions such a robot must alter to effectively change a colony's foraging decision.

We study with a mathematical model how foraging choices could effectively be affected by robots. The model implements equations capturing the core mechanics of collective decision-making in honeybee foraging. We extended a model by Seeley et al. (1991) by adding the effect of waggle dancing robots in order to be able to tackle our two main research questions:

(Q1) Can a biomimetic robot alter a colony's decision-making in a significant way by imitating waggle dances?

(Q2) How does this effect scale with the number of robots?

Such a model-driven analysis combined with ALIFE biomimetic robot research may ultimately help to create biohybrids that are helpful in the conservation of honeybees and the dependent ecosystems. Our focus is on predicting the consequences of waggle dancing robots' influence onto the colony's decision-making. In order to do this, our model covers the foraging and recruitment process in a bee colony. We use a classic experiment of decision-making (Seeley et al., 1991) as a benchmark. The objective of the robots is to guide the bees' foraging in a qualitatively significant way, so that they neglect a specific foraging target that they would naturally choose.

Modeling

The processes covered by our model are: (1) Bees collect nectar from a source, (2) then they hand over their nectar loads to storer bees, (3) then they either give up their source, (4) or they visit the same source again, (5) or they advertise their foraging source as waggle dancers. The decision-making is a probabilistic process of the colony, as the naive bees search for dancers by chance at the dance floor region of the hive, where multiple dancers are competing for attention. Biomimetic robots may influence the colony's global decision-making via dance activity that they add artificially to these natural processes.

For the sake of simplicity our model is based on Seeley's deterministic ODE model (1994) , a quasi-standard model in this field, predicting collective decisions as a result of waggle dance durations dependent on the energetic net profitability of visited sources: The higher the quality of a source is, the longer will be the dance time for this source, ultimately increasing the recruitment for it. Dance times scale linearly with a food source's net energetic efficiency (Seeley, 1994), and depend on the colony's current nectar needs. Slopes and offsets of these linear functions correlate negatively (Schmickl et al., 2010). Figure 1 shows a waggle dance submodel (lower part) and a submodel of forager allocation to food sources (upper part). We extended the model by a waggle dancing robot which acts as an additional dancer for a specific target, enhancing its recruitment rate of foragers. It changes the probability of a naive bee to encounter and to follow a dance for the advertised source, as is modelled by equ. (1)

$$p_A^{follow} = \frac{D_A^{bee} \cdot d_a^{bee} + D_A^{robot} \cdot d_a^{robot}}{D_A^{bee} \cdot d_a^{bee} + D_A^{robot} \cdot d_a^{robot} + D_B^{bee} \cdot d_b^{bee}} = 1 - p_B^{follow}, \quad (1)$$

where the variables $D_A^{bee}(t)$,$D_B^{bee}(t)$ model the number of waggle dancers for the two food sources "A" and "B" at time

t, the variables $d_a^{bee}(t)$, $d_b^{bee}(t)$model the numbers of dance rounds these bees perform on average, and $D_A^{robot}(t)$, $d_a^{robot}(t)$are the equivalent variables for the dance robots. The forager population size was adjusted to respect the empirical data.

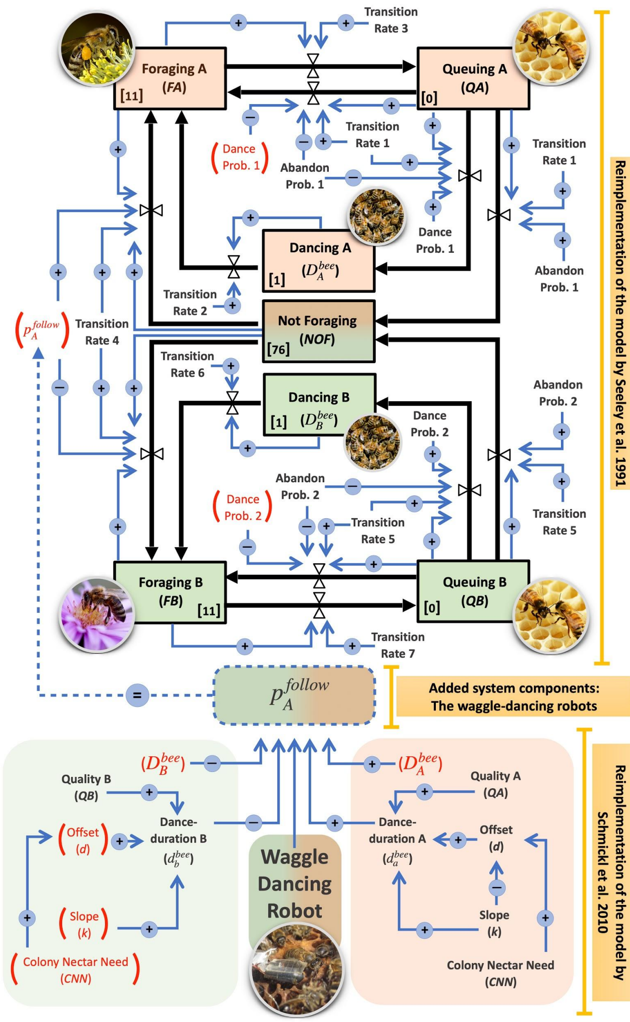

Fig. 1: Representation of our model as a Stock & Flow diagram that depicts our system of 7 ODEs. Rectangles: stocks holding quantities (bees), initial values are given in square brackets; Black arrows: flows between stocks, describing change of quantities; Blue arrows: dependencies between components with correlation indicator (+/-); Red variables in parentheses are already defined in other parts of the diagram. For more details on constants and equations see Seeley et al. (1991) and Schmickl et al. (2010).

Results

The predictions of our model without any dance robots fit well to the reported empirical data (Fig. 2a) of the food source choice experiment by Seeley et al. (1991): A honeybee colony was offered a choice between two equidistant food sources of significantly different quality during the morning, a situation which was then suddenly switched at noon and stayed like this for the afternoon. Answering Q1, our model predicts that one effective dancing robot can delay the decision-making beyond the duration of the experiment but not fully prevent it in the long run. Concerning Q2, we see that two or more dancing robots (per 100 foragers) can robustly alter a colony's collective foraging decision (Fig. 2b), even if the robots are advertising the energetically less profitable foodsource. The predicted number of foraging bees on the advertised food source correlates positively with the number of robots. (Fig. 2b). However, this effect saturates quickly with more robots deployed. Regardless of the number of robots, the foraging for an inferior target will be lower than for a good one (Fig. 2b).

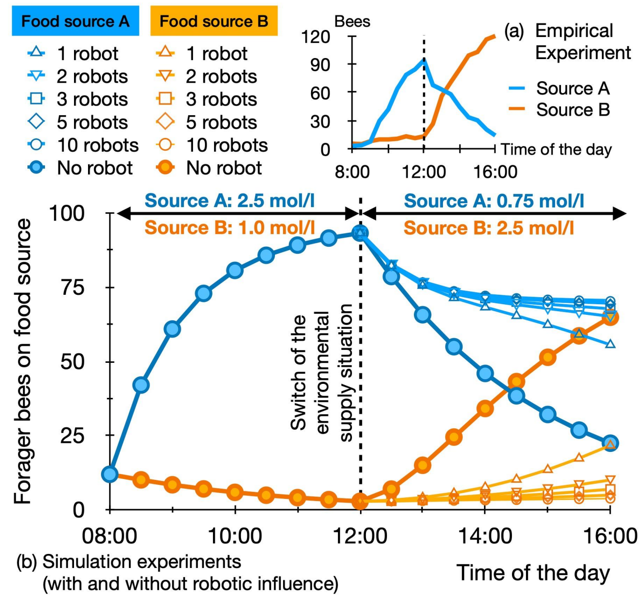

Fig. 2: (a) Empirical experiment data is redrawn from Seeley et al. (1991) and compared to (b) our model's predictions of a comparable simulation experiment with and without robots.

Conclusion

Our model predicts that a few biomimetic robots can effectively guide honeybees' foraging decision-making. Still, one robot that emulates dances might not be enough to make a significant impact. Our results show that it might be a feasible path to make safer or ecologically more important food sources more attractive to bees, even if these sources are energetically less profitable. However, these induced energetic losses must be compensated somehow, e.g., by providing the colony with thermal energy to reduce heating costs in brood rearing or by offering extra food. Targeted pollination and increasing plant diversity, along with an induced avoidance of contaminated agricultural areas, seems to be a feasible ultimate potential of such a technology. The success of the required transition from theory to practice has yet to be researched. Here we give a preliminary report about our key finding, more detailed studies that look at the overall pollination effect and at floral situations with more complex nectar distributions and dynamics will follow.

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