Design and Implementation of Hardware Platform for Monitoring Honeybee Activity

Uroš Pešović, Siniša Ranđić, Zoran Stamenković

Abstract— **Remote monitoring of beehive colonies becomes an interesting topic in the field of precision agriculture. One of the most relevant parameters which give insight into beehive health is the bee activity at beehive entrance. This paper presents design of a dedicated bee counter which is located at the beehive entrance to count bees entering or leaving the beehive. Paper also presents the counter's implementation on FPGA platform which can be used for field measurements of the bee activity.**

Index Terms— **FPGA; counter; honeybee; photo interrupter sensor.**

I. Introduction

European honeybee is one of the most important insect spices for humankind, both as source of nutritious honey and well as the most efficient insect pollinator in agriculture. The EU parliament noted in resolution T6-0579/2008, that 79% of the world's food supply is dependent on honeybees as pollinators. Honeybee colonies are affected by widespread usage of pesticides in agriculture, pollution and climate change as well as invading pests brought from other regions of globe. Emerging problem in beekeeping is colony collapse disorder (CCD) when the majority of worker bees in a colony disappear without known reason and leave behind a queen, after which queen dies out.

Thus, bee hives needs to be monitored by beekeepers in order to take pre-emptive actions in order to help bee colony to overcome arisen problems. Most commonly, beehive monitoring focused on periodic manual inspections by beekeepers, which could be impractical and time and cost expensive. Remote monitoring enables monitoring by integrating sensors in beehives which readings can be used in determining activity of beehive colony [1]. Activity of beehive colony is usually measured as number of worker bee's entering/leaving beehive per unit of time. Activity of beehive can be monitored using various parameters, such as weight balance of beehive, processing of audio/video signals or dedicated counters on beehive entrance. Weight measurement requires high resolution and accuracy in order to measure the bee activity and main drawback is that activity of each bee entering beehive is cancelled with one leaving the beehive [2]. Audio/ video processing provides rough measurement of beehive activity and requires significant processing resources, but results are not accurate [3, 4]. Dedicated counters located at beehive entrance are the most practical for measuring beehive activity [5]. Bees are guided through multiple counting channels called bee passageways where bees entering/leaving beehive are counted individually. Presence of beehive passageway also prevents pest such as hornets, bumblebees and mousses to enter beehive and cause damage to beehive colony. By measurement of beehive activity, numerous situations can be detected and beekeeper can be warned to take certain actions. For example, swarming represents reproduction event in which old queen suddenly leaves beehive with half of the worker bees in order to find new nest, leaving new queen in beehive. When large departure of bees is detected, beekeeper is warned and it tries to catch departed bee colony into new empty beehive. In addition, beehive colony can came to be pillaged by other beehive, which can be detected by huge income of bees in bee colony. Invading bees in short, time steal collected honey and devastate bee colony by killing worker bees and queen. When detected, beekeeper needs to react promptly in order to prevent pillage and damage to its beehive colonies. Also activity of the beehive can be correlated to environmental conditions (air temperature, air humidity, part of day or season) in order to determine health of beehive colony.

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II. Structure of the Bee Counter

Presence and heading direction of bee in passageway can be determined using various types of sensors, such as mechanical, capacitive, passive infrared, ultrasonic or optical sensors. Photo interrupter sensor, presented in Fig. 1 is the most convenient type of optical sensor for bee detection.

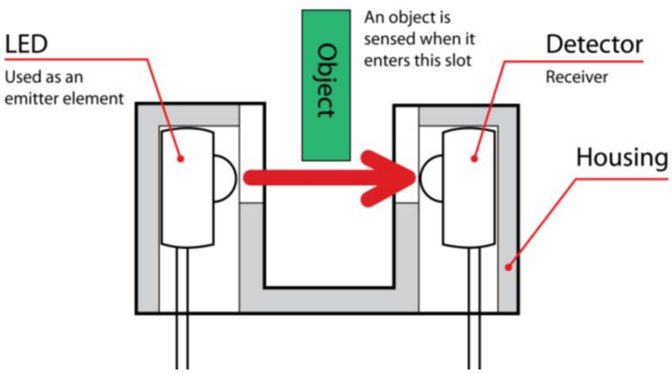

Figure 1. Structure of photo interrupter sensor

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Photo interrupter sensor consists of infrared LED emitter optically coupled to phototransistor detector. Emitter and detector are integrated into plastic case with air gap in which object can block detector, so presence of object can be easily detected. Infrared LED emitter and detector are matched to near visible infrared wavelength of 950 nm, in order to exploit sunlight's infrared gap and prevent interference from stray sunlight. Bee's vision is much less sensitive to infrared light compared to humans, so bees would not be affected when pass through air gap of photo interrupter sensor. Physical dimensions of photo interrupters for use in bee passageway are defined by physical dimensions of worker bee, drones and queen bee. Typical worker bee is around 12 mm long with height and width of are around 5 mm. Drones and queen bee are bigger than worker bee and their length is around 16 and 20 mm respectively, while their height and are around 7 mm. Physical dimensions of photo interrupter air gap need to be at least 8 mm in order to enable unobstructed movement of bees in and out of the beehive. The most convenient photo interrupter available on market for this purpose is Omron EE-SX1070 [6] with air gap width and height of 8 mm. Outer width of this photo interrupter is 17.7 mm, outer height is 10 mm, while depth is 6 mm. When bee walks through photo interrupter air gap it will block IR light and its presence will be easily detected by changing logic state of phototransistor detector from logical zero to logic one as shown in Figure 2.

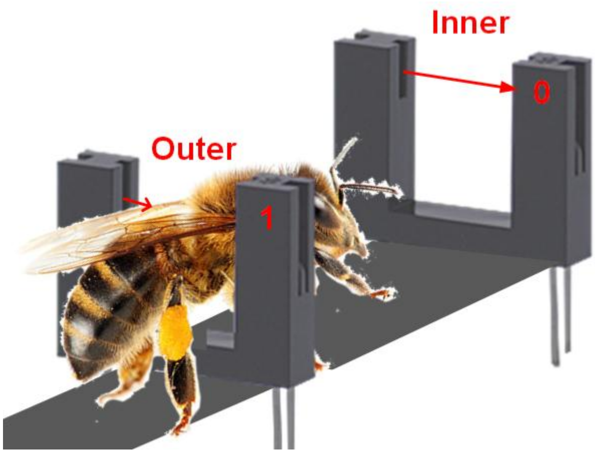

Figure 2. Worker bee entering bee passageway

In order to detect bee entering/leaving beehive, at least two photo interrupters per bee passageway are necessary; inner and outer one placed side by side to each other. When bee tries to enter beehive trough passageway, it first blocks outer photo interrupter's light ray and then inner photo interrupter's light ray. In case inner interruption is followed by outer interruption bee leaving beehive is counted. Inner and outer photo interrupters are separated by certain distance of around 6 mm which bee has to pass within certain time. Average walking speed of worker bee is between 20 and 120 mm/s [7], so bee should interrupt both photo interrupters in succession within period between 50 ms and 300 ms. Interruption outside this timeout period is considered as incorrect counting. Third photo interrupter sensor can be added in the middle between inner and outer sensor in order to increase accuracy of counting. In case of two sensors, false counting is possible when two bees simultaneously try to enter/leave trough same passageway. Direction of bees in passageway can be determined using finite state machine (FSM). A state machine is a sequential circuit that advances through a number of states if certain conditions are met. Two-bit output vector is used for indicating direction of bee in passageway, where MSB bit indicates incoming bee and LSB indicates outgoing bee.

Typical length of beehive landing platform is around 300 mm and it can accommodate 16 parallel bee passageways. Each passageway employs one FSM whose outputs are fed to entering and leaving priority selectors. These priority selectors are used to enable accurate incrementing of global counter from multiple bee passageways. Each priority selector selects appropriate output form highest priority FSM and enables incrementing of global counter. After incrementing global counter form particular FSM, priority selector resets that FSM to enable detection of another bee in that passageway. Priority selector then selects following FSM with highest priority and increment global counter until all detected bees by FSM are counted. Bee counter can be implemented either by microcontroller of FPGA. Advantage of FPGA implementation is in large number of available I/O pins and ability to parallel processing of multiple bee passageways.

III. Realization of Bee Counter

Bee counter realized on FPGA platform is composed from bee passageway printed circuit board which is connected to the FPGA development board as presented on Figure 3.

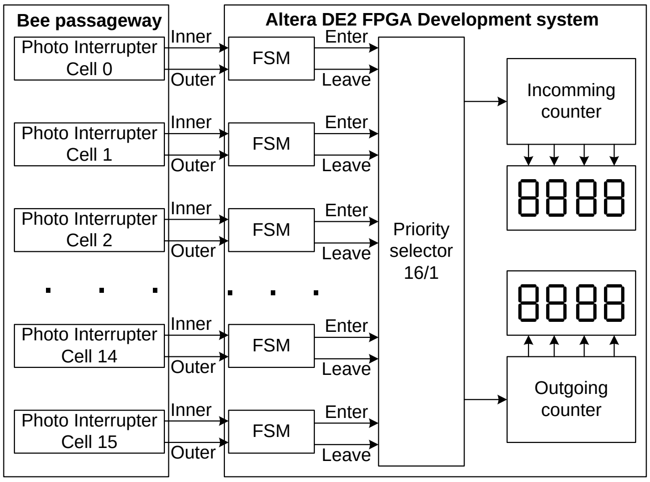

Figure 3. Structure of bee counting system

A. *Bee passageway*

Bee passageway represents printed circuit board which contains 16 pairs of photo interrupters, which are used for detecting presence and direction of bees at beehive entrance. Infrared LED diodes from one photo interrupters are connected to the 3.3 V power supply of FPGA development board via resistor which sets current of LED diode to 15 mA. Phototransistor detector is connected via pull up resistor to power supply to enable detection of logical one when photo interrupter light ray is interrupted by passing bee. Power consumption of entire bee passageway containing 32 photo interrupters is around 500 mA. Layout of several cells of bee passageway PCB is presented on Figure 4.

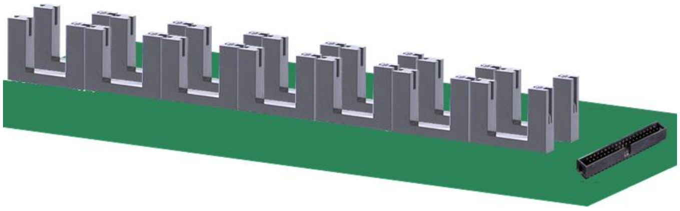

Figure 4. Layout of bee passageway PCB

B. Finite state machine

Finite state machine used for detecting bee in passageway is divided into two parts as presented in Figure 5. Left part is used for bees leaving beehive and right part for bees entering beehive with initial state s0 in the middle. When bee first triggers outer photo interrupter FSM enters state s1 and timer is initiated. If inner photo interrupter is triggered in specified period between 50 ms and 300 ms, FSM can advance in following state s2. Otherwise, activation of timeout will return FSM to initial state. When bee enters beehive, it will unblock both photo interrupters and FSM will advance in state s3 and one entering event Enter_CNT is set for counting. After successful counting, entering event is reset by counter using Enter_RST signal.

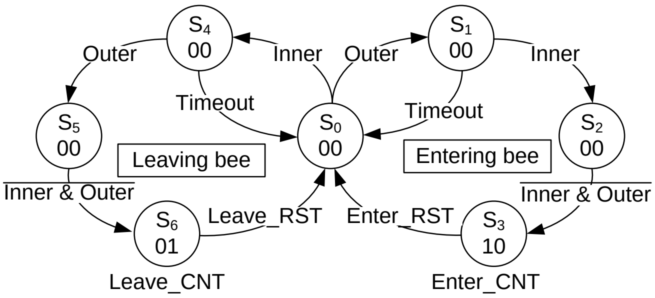

Figure 5. Finite state machine for detecting bees in passageway

State machine in VHDL is declared using enumeration type for the states form s0 to s6, and state transitions are defined in a process statement. State machine can advance on every positive edge of the CLK clock signal to next state, if necessary control condition is met. Clock signal is supplied form digital oscillator operating at 50 MHz, located on FPGA development system.

C. Priority selectors

Role of priority selector is to enable concurrent counting form sixteen FSM which are connected to its inputs. Each FSM is given priority to enable that only one FSM can be serviced at one clock interval in order to increment global counter. Two priority selectors are implemented; one for counting bees entering the beehive and the other for counting bees leaving the beehive. After selection of highest priority FSM, priority selector sends increment impulse to its corresponding global counter and resets FSM to initial state. Waveform of servicing sixteen simultaneous counting requests represented by vector LEAVE_CNT is represented on Figure 6. Priority selector selects request with the highest priority LEAVE_CNT(15) originating from FSM15, after which in next clock cycle clocks global counter using LEAVE_CLK signal and send reset signal LEAVE_RST to FSM15. Priority selector then services following FSM with highest priority and generates another clock for global counter. After servicing all FSM requests, priority selector stops increments generation until new FSM request appears.

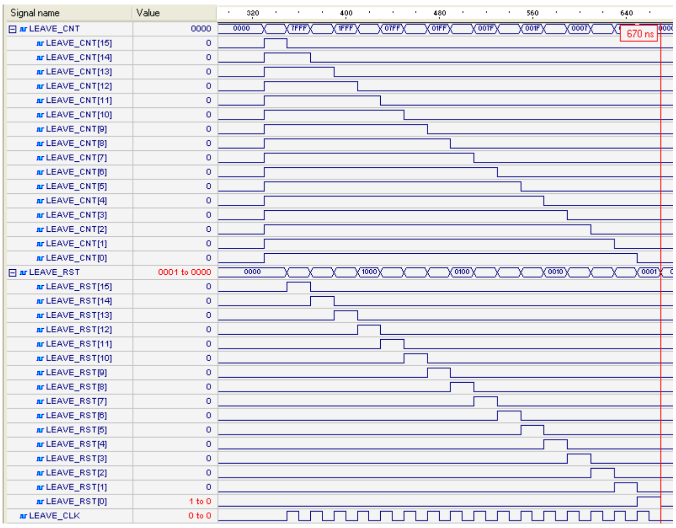

Figure 6. Waveforms of priority selectors

D. Global counters (incrementer)

Global counters are used to count and display overall number of bees which entered or left beehive in certain period. They are realized as four digit decimal counters with integrated BCD to seven-segment decoder to enable displaying its value directly to user of four digit seven segment LED displays. In addition, current counting value is available to host microcontroller for further processing and transmission. Waveform of simultaneous counting requests from sixteen FSM is presented on Figure 7.

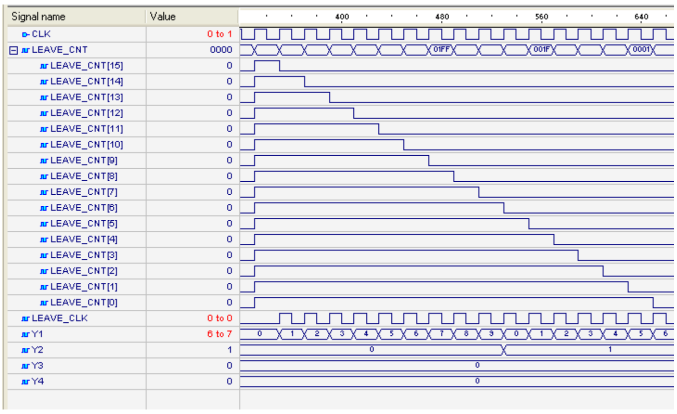

Figure 7. Waveform of leaving decade counter incrementing

E. *FPGA implementation on Altera DE2*

Proposed structure of bee counter is implemented in VHDL and synthetized for Altera Cyclone II FPGA chip. Altera's Cyclone II FPGA family [8] is 1.2-V based SRAM, designed on an all-layer-copper 90-nm process technology. Altera DE2-115 if FGPA development system is based on Altera Cyclone II 2C35 FPGA, which contains 33,216 logic elements [9]. Each logic element features: four-input look-up table (LUT), programmable register, carry chain connection and register chain connection. DE2 development system also includes 4 Push-buttons, 18 switches, Two 40-pin Expansion Headers, 9 Green and 18 Red User LEDs and one 16 x 2 LCD Module.

Proposed bee counter synthetized in Quartus II software requires 1.890 logic elements, 662 dedicated logic registers, and 90 I/O pins. Project is programmed on Altera DE2 development system using USB Blaster interface and layout of laboratory model is presented in Figure 8.

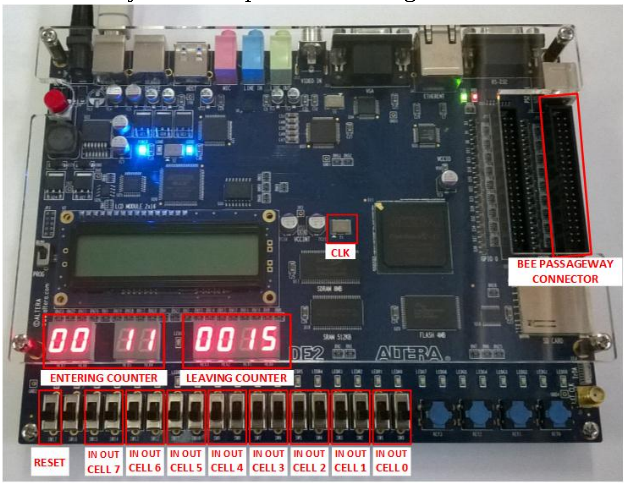

Figure 8. Implementation and testing of beehive counter on Altera DE2

Operation of bee counter is tested without bee passageway, using switches available on Altera DE2 development board. Eight passageways cells form Cell 0 to Cell 7 are emulated using 16 switches. Left switch in one cell represents logic state of inner photo interrupter while right one represents outer photo interrupter in bee passageway. Clock is provided using integrated clock source while the reset is connected to leftmost switch. Number of bees entering beehive is presented on four leftmost seven-segment LED displays, while other four are used to present number of bees that left beehive. By activating switches in required succession for entering/leaving event we were able to increment corresponding counter. Also simultaneous activation of multiple cells switches enabled accurate counting of these multiple entering/leaving events.

Bee passageway PCB will be connected to 40-pin expansion port connector and implemented in field in spring of 2017 when beehive colonies emerge from winter hibernation. Accuracy of counting process will be compared by manually counting bees, which are filmed by camera at beehive entrance. By observation of implemented system in real scenario, we will be able to improve performance of FSM in order to enable more accurate detection of a bee entering or leaving the beehive. Developed VHDL model is planned to be implemented as a dedicated bee counter inside FPGA design which includes embedded node with ARM Cortex M IP core. Remote monitoring will be provided via wireless connection provided via IEEE 802.15.4 or IEEE 802.11 networks.

IV. CONCLUSION

Remote monitoring of beehives provides better insight into state of beehive colony, enables increase in beekeeping efficiency, and reduces reaction times on detecting of critical conditions, which could endanger beehive colony. In this paper, we presented dedicated counter realized on FPGA platform, which can be used for measuring activity of beehive by counting bees which enter or leaving the beehive. Realized counter will be tested in real conditions and it design will be improved to achieve high counting accuracy. In future, we are going to integrate the bee counter as a peripheral block into an embedded FPGA platform with core processor.

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REFERENCES

[1] W. G. Meikle, N. Holst, Application of continuous monitoring of honeybee colonies, Apidologie, vol.46, pp.10–22, 2015.

[2] S. Kordić Evans?, “Electronic beehive monitoring – applications to research”, Proc. 12th International Symposium of the ICP-PR Bee Protection Group, Ghent (Belgium), 2014.

[3] J. Campbell, L. Mummert, and R. Sukthankar, Video monitoring of honey bee colonies at the hive entrance ??

[4] V. Kulyukin and S. K. Reka, “A computer vision algorithm for omni-directional bee counting at langstroth beehive entrances”, Int'l Conf. IP, Comp. Vision, and Pattern Recognition, 2016.

[5] J.A. Jiang, C.H. Wanga, C.H. Chen, M.S. Liao, Y.L Su, W.S. Chen, C.P. Huang, E.C. Yang, C.L. Chuang, “A WSN-based automatic monitoring system for the foraging behavior of honey bees and environmental factors of beehives”, Computers and Electronics in Agriculture, vol.123, pp.304–318, 2016.

[6] Omron Corporation, EE-SX1070 Photomicrosensor, Datasheet

[7] H. Schfine, “Optokinetic speed control and estimation of travel distance in walking honeybees”, Journal of Comparative Physiology A, vol.179, pp.587–592, 1996.

[8] Altera Corporation, Cyclone II Device Handbook: Volume 1, San Jose, California, USA

[9] Altera Corporation, DE2 Development and Education Board: User Manual v 1.6, San Jose, California, USA